The elements of natural or experimental philosophy

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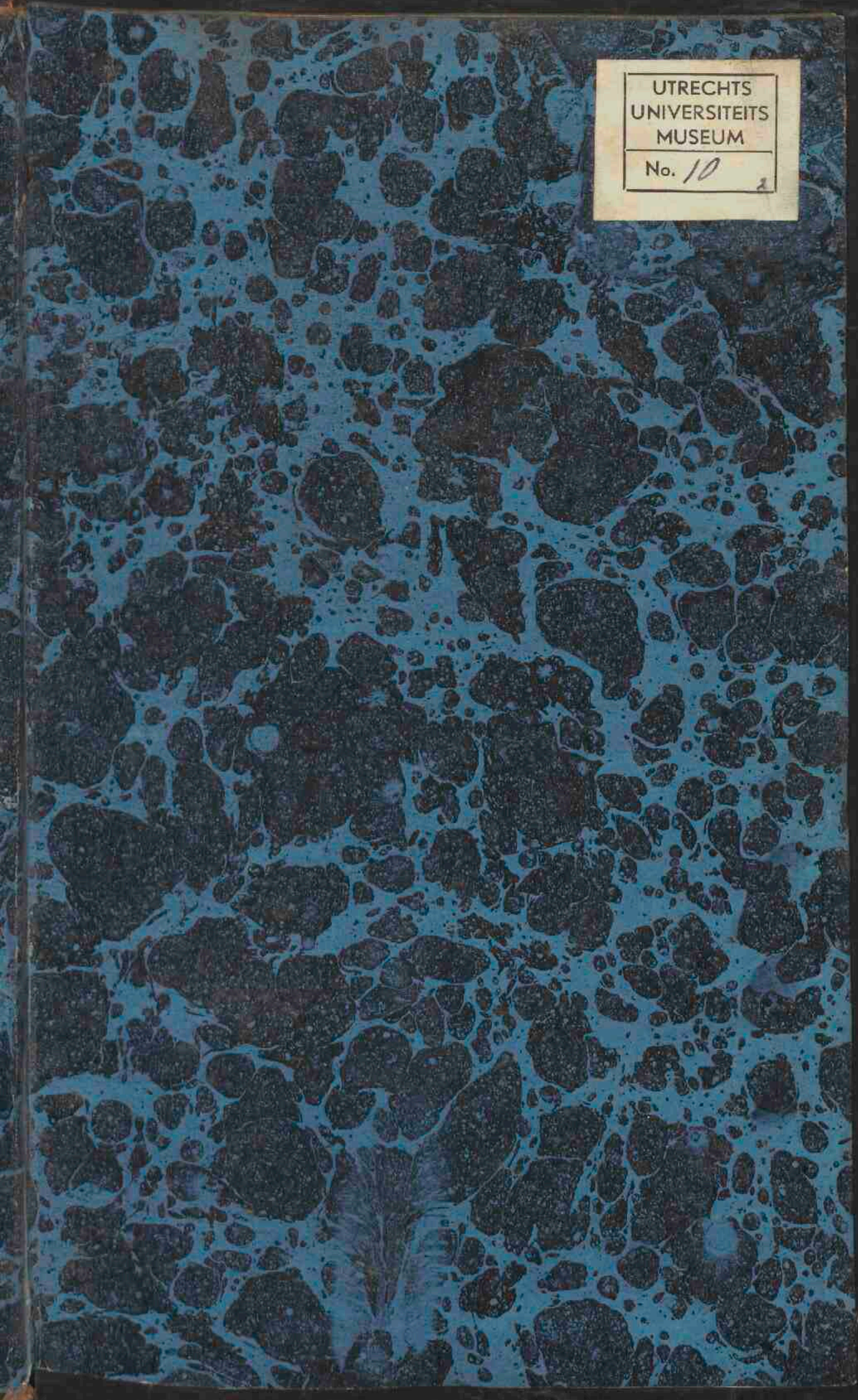

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BY

TIBERIUS CAVALLO, F.R.S. &c.

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IN FOUR VOLUMES.

VOL. I.

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NATURAL PHILOSOPHY.

PART II.

OF THE PECULIAR PROPERTIES OF BODIES.

IT would have been uſeleſs in the preceding part of this work to have enumerated, or to have arranged under any claſſical order, the various bodies of the univerſe; ſince the properties which formed the ſubject of that part, belong indiſcriminately to bodies of every denomination. In treating of one of thoſe properties, viz. of the mobility of matter, and particularly of the colliſion of bodies, one difference only was noticed, namely, that which exiſts between elaſtic and non-elaſtic bodies; but that difference neither demanded a particular diſcrimination of bodies, nor could it with propriety be introduced in any other part of the work. We alſo, in explaining the doctrine of motion, applied its laws to ſolids only, not becauſe fluids

fluids are exempt from thoſe laws, as far however as their nature admits of their being placed in circumſtances ſimilar to thoſe of the ſolids; but becauſe the mechanic of fluids contains certain other laws which are not applicable to ſolids; hence the particular examination of the equilibrium and of the motion of the fluids, was reſerved for the preſent part.

We are now going to treat of the peculiar properties of bodies, viz. of ſuch as render one piece of matter, or ſet of bodies, different from another piece of matter, or other ſet of bodies; and of ſuch properties there are ſome which belong to a great number of bodies, though not to all; others which belong to a few; and, laſtly, there are other properties, which belong to ſingle bodies only. Thus water, oil, ſpirit of wine, and air, are all *fluid* ſubſtances, ſo that by that fluidity they are diſtinguiſhed from ſtones, metals, wood, bones, &c. which are all *ſolid* ſubſtances. But, though water, oil, ſpirit of wine, and air, be all called fluids; yet the firſt three are diſtinguiſhed from the laſt, by this, viz. that they are not compreſſible into a narrower ſpace by the application of any mechanical force, at leaſt not in any remarkable degree; whereas air may be eaſily compreſſed into a narrower ſpace. Hence water, oil, and ſpirit of wine, are ſaid to be non-elaſtic fluids; but air is ſaid to be an elaſtic fluid. Farther, though water, oil, and ſpirit of wine, be all three non-elaſtic fluids,

fluids, yet the firſt may be diſtinguiſhed from the other two, by its not being capable of inflammation; whereas oil and ſpirit of wine may be eaſily inflamed and burned away. Yet though theſe two agree in the property of being inflammable, they may however be eaſily diſtinguiſhed from each other by means of other peculiar properties; common oil, for inſtance, is much leſs fluid than ſpirits; it alſo feels clammy to the fingers, which ſpirit of wine does not; it is leſs inflammable, and leſs evaporable than ſpirits, &c.

This ſhort ſketch of the nature and variety of the natural properties of bodies, will ſufficiently manifeſt the multiplicity of particulars which muſt be noticed in the preſent part of theſe elements; and will, at the ſame time, point out the neceſſity of preſerving as much order and perſpicuity, as the intricate nature of the ſubject can admit of.

With this view we ſhall begin by making a ſlight, but general, ſurvey of the Univerſe, or rather, of the bounds of human knowledge relative to the number and variety of natural bodies; whence the reader may form ſome idea of the extent, variety, and importance, of the ſubject. But previous to this, it will be proper to make the following obſervation.

It is a rule in elementary compoſitions, to explain thoſe articles firſt, which may elucidate what follows;—to take nothing for truth, unleſs it has been previouſly proved; and not to mention any thing which has not been already deſcribed. But the ſtrict adherence to this rule is impracticable in natural philoſophy, wherein hardly any thing can be mentioned, which does not owe its exiſtence to the previous exiſtence of ſeveral other things, which cannot have been all previouſly deſcribed. Thus, in ſpeaking of the fuſibility of metals, we muſt naturally mention the thermometer; and in deſcribing the thermometer, we muſt naturally ſuppoſe the previous knowledge of the fuſibility of glaſs, and of the nature of quickſilver, which is the metallic ſubſtance moſtly uſed for the conſtruction of that very uſeful inſtrument. The reader, however, need not be under any apprehenſion of being miſled or confuſed; for whenever any article is mentioned without its having been previouſly explained, he may be aſſured, in the firſt place, that the particular deſcription of that article is not neceſſarily required in that place; and ſecondly, that the proper deſcription of that article will be found in ſome other more appropriate part of the work.

CHAPTER I.

CONTAINING AN ENUMERATION OF THE VARIOUS KNOWN BODIES OF THE UNIVERSE, UNDER GENERAL AND COMPREHENSIVE APPELLATIONS.

THE moſt diſtant objects, that are at all perceivable by any of our ſenſes, are the luminous coeleſtial bodies, amongſt which the Sun is the grandeſt and the moſt admired of the creation. Its ſplendor, its heat, and its beneficial influence, have always excited the particular attention of the human ſpecies, and have obtained the adoration of all thoſe nations, which have not been bleſſed with the light of Revelation. Next to it is the Moon, whoſe apparent ſize nearly equals that of the Sun; but its ſplendor is vaſtly inferior. The other numerous bright objects of the heavens differ from each other in ſize and luſtre; but in thoſe reſpects they all appear greatly inferior even to the Moon. Amongſt them there are ſix, which are ſeen to move with apparent irregularity, but under certain determinate laws, through certain parts of the heavens; whilſt the others appear to remain at the ſame unalterable diſtance from each other.—The former are called *Planets*, and their particular names are, *Mercury*, *Venus*, *Mars*, *Jupiter*, *Saturn*, and the

Georgian Planet: but it will be ſhewn hereafter, that the Earth we inhabit is likewiſe a planet, which renders the planets ſeven in number. The latter are called *Stars*, the principal of which have likewiſe obtained particular names; but they are too numerous to be inſerted in this place.

Beſides the Stars properly ſo called, and the planets, which are always viſible to the inhabitants of the Earth, ſeveral other luminous objects are at times ſeen in the heavens, which appear for a conſiderable time, move in a manner apparently more irregular than the planets, then diſappear, and perhaps make their appearance again after a long period of years. Theſe are called *Comets*.

By means of the teleſcope it has been diſcovered, that four ſmall luminous objects revolve at certain diſtances round the planet Jupiter; ſeven ſuch bodies revolve round the planet Saturn, and ſix revolve round the Georgian Planet. Thoſe ſmall revolving bodies are called *Satellites*, or *Moons*; for in fact the Moon itſelf will be ſhewn to be a Satellite, which moves round the Earth, in the ſame manner as the abovementioned ſatellites revolve round their reſpective planets in ſtated periods.

The ſcience which enumerates thoſe coeleſtial objects, which deſcribes their peculiar appearances, which examines and calculates their movements, and which renders that knowledge uſeful to the human ſpecies, is called *Aſtronomy*, the elements of which

which will be explained in the fourth part of this work.

The celeſtial bodies which have been juſt mentioned, and ſuch as fall under the cognizance of Aſtronomy, do all move under certain laws, which, even with reſpect to the Comets, have been in a great meaſure inveſtigated and aſcertained. But there are ſeveral other objects, either luminous or opaque, which appear in the ſky at uncertain times, and which do not follow any known regularity of motion; ſo that they very ſeldom appear twice in the ſame place, and of preciſely the ſame ſhape. Theſe are, for very ſtrong reaſons, ſuppoſed to be much nearer to us than the Moon, which is the neareſt to us of all the celeſtial bodies that have a known regularity of motion. They are collectively called *Meteors*, whence the particular examination of their origin, of their appearances, and of their influence, or of their effects, forms the ſubject of *Meteorology*, which is a very conſiderable branch of Natural Philoſophy.

The principal objects of Meteorology are, 1. Thoſe luminous appearances, which are commonly called *Falling Stars*, or *Shooting Stars*, the largeſt of which are more particularly called *Meteors*. 2. The quick moving light, which is ſeen at times in the ſky, eſpecially about the North and South Poles, and which has hence been denominated the *Aurora Borealis*, and *Aurora Auſtralis*, or *Northern* and *Southern Lights*. 3. The *Rain-bow*. 4. *Halo's*, or *Corona's*

Corona's, viz. thoſe ſteady white circles which are ſometimes ſeen about the Sun and the Moon. 5. *Parhelia*, or *Mock Suns*, and *Paraſelenae*, or *Mock-Moon*. 6. The *Zodiacal Light*. 7. Other luminous appearances more irregular and leſs remarkable than the preceding, which have obtained, from their more uſual ſhapes, ſituations, &c. the various names of *Draco Volans*, viz. *Flying Dragon*, or *Flying Kite*; *Luminous Arches*; *Luminous Clouds*; *Ignis Fatuus*, vulgarly called *Will with a wiſp*, or *Jack in a lanthorn*, or *Jack-a-lanthorn*; the *Fata Morgana*, &c. 8. *Thunder* and *Lightning*. 9, *Vapours*, *Fogs*, *Miſts*, and *Clouds*. 10. *Rain*, *Hail*, and *Snow*. 11. *Water Spouts*. 12. *Winds*, under the various names of *Trade Winds*, *Monſoons*, *Gales*, *Whirlwinds*, &c. . 13. *Storms*, and *Hurricanes*.*

Some authors have reckoned the natural formation of ice, or the froſt, as alſo earthquakes, volcanos, &c. amongſt the meteors; but it will be much better to confine the word meteor to its original ſignification, viz. to ſomething that takes place in the ſky above us, but nearer to us than the Moon.—The nature, origin, and effects of the above enumerated meteorogical objects, as alſo of volcanos, of earthquakes, &c. will be deſcribed in different parts of theſe elements.

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* Thoſe objects of meteorology have been uſually ſaid to be of three kinds, viz. *fiery*, *watery*, and *airy*, *meteors*. But this diſtinction is both uſeleſs and improper.

We muſt laſtly enumerate the various bodies which form the Earth, or the planet we inhabit.

A variety of obſervations, experiments, meaſurements, and incontrovertible arguments, the principal of which will be mentioned hereafter, have proved that this Earth is not a perfect ſphere; but that it is a little flattened on two oppoſite parts, which give it the figure of an *oblate ſpheriod*; the longeſt diameter of which has been reckoned equal to 41960862 Engliſh feet, or 7947 Engliſh miles; the ſhorteſt diameter has been reckoned equal to 41726516 Engliſh feet, or 7902,7 Engliſh miles; the difference of the two diameters being 234345,6 feet, or 44,4 miles.*

The

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* See De la Lande's Aſtronomy, vol. III. De la Figure de la Terre et de ſon applatiſſement; where, viz. in §. 2690, and 2693, the two diameters are ſhewn to be equal to 6562024, and 6525376 French toiſes, from which the above-mentioned lengths have been derived; a French toiſe being equal to 6,3945 Engliſh feet.

Sir Iſaac Newton, ſuppoſing the earth to be of uniform denſity, aſſigned for the difference between the equatorial and polar diameters $\frac{1}{230}$ part of the former. Boſcovich, taking a mean from all the meaſures of degrees, found the difference of the two diameters equal to $\frac{1}{248}$. From other meaſurements made in various parts and calculated by different able mathematicians, this difference has been reckoned equal to $\frac{1}{311}$ or $\frac{1}{300}$ by de La Lande; to $\frac{1}{321}$ by de La Place; to $\frac{1}{307}$ by Sejour.—Theſe latter reſults agree pretty well with the obſervations of the length of the pendulum made

The ſurface of the Earth conſiſts of land and water variouſly intermixed. The land is uſually divided into, 1. *Continents*, or very large tracts comprehending ſeveral countries, ſtates, &c. 2. *Iſlands*, or ſpots of dry land, having water all round. 3. *Peninſulas*, or ſpots of dry land ſurrounded by water, excepting a ſmall neck or communication with ſome other land. 4. *Iſthmuſes*, or necks of land, which join the peninſulas to other land. 5. *Promontories*, or high lands extending themſelves into the ſea, the extremities of which are called *Capes* or *Head-lands*. And laſtly, *Mountains*, which are parts of the land conſiderably elevated above the adjacent country; the ſmalleſt of which are called *Hills*.

The watery part of the ſurface is uſually divided into, 1. *Oceans*, or vaſt collections of ſalt water, viz. the largeſt diviſions of the watery part of the ſurface. 2. *Seas*, or parts of oceans, cloſe to, or between ſome countries. 3. *Gulfs* or *Bays*, which are ſeas having land all round, except on one ſide, by which

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made in different latitudes; ſo that upon the whole $\frac{1}{300}$, or a fraction not much differing from this, ſeems to be the neareſt to the truth. The cauſes of diſagreement between the reſults of different meaſurements, probably are the imperfection of inſtruments, the partial attraction of mountains, and the unequal denſity of the materials within, and at no great diſtance from the ſurface of the earth. See Profeſſor Playfair's paper on the fig. of the Earth in the Tranſ. of the R. S. of Edinburgh, vol. V. P. I.

they communicate with other ſeas or oceans. 4. *Straits*, or *Friths*, being narrow branches of the ſea between two contiguous lands, or narrow paſſages from one ſea to another. 5. *Lakes*, or collections of water in ſome inland place. And 6. *Rivers*, or *Streams* of *Water*.

The particular deſcription of thoſe parts, as alſo of the political diviſion of the Earth, form the ſubjects of *Geography* and *Hydrography*.

There are ſeveral hollows or natural pits in the Earth; but they either do not deſcend, or could not be examined, to any great depth. Deep pits have alſo been made by human art; but the deepeſt of them do not exceed 2400 feet, or leſs than half a mile; ſo that the induſtry of man has not been able to penetrate ſo far below the ſurface of the Earth as half a mile, which is a very ſhort diſtance indeed, when compared with the abovementioned lengths of the diameters. So that whatever lies below that depth is to us utterly unknown.

The materials which have been extracted from thoſe excavations are not in general of a nature different from thoſe, which in ſome particular places have been found immediately upon the ſurface of the earth.

Upon that ſurface a vaſt variety of objects is to be obſerved; but thoſe various objects, together with thoſe that are dug, have been uſually arranged under three grand diviſions, which are naturally ſuggeſted by their more ſtriking properties, and which

which have been emphatically called the *three Kingdoms of Nature*; viz. the *Animal Kingdom*, which comprehends all thoſe ſelf-moving, organized bodies, of which the human being forms one ſpecies. The *Vegetable Kingdom*, which comprehends all thoſe organized bodies called *plants*, which grow by an enlargement of parts, have a certain period of life or of exiſtence, but are attached to a particular part of the ſoil, from which they derive the greateſt part of their nouriſhment. And laſtly, the *Mineral Kingdom*, which comprehends all the other bodies of the Earth; for all the others are ſometimes found within the Earth, whereas living animals and living plants are not to be found buried at any conſiderable depth below the ſurface of the Earth.

Every one of thoſe three grand diviſions is ſubdivided into a variety of ſubordinate ſubjects. Thus the particular enumeration and claſſification of all living creatures, or organized bodies, which give marks of ſenſation, which continue their kinds according to invariable laws, and which are found in the ſtate of embryo, infancy, maturity, old age, or death, forms the ſubject of *Zoology*.—*Anatomy* examines and deſcribes the internal and external parts of the animal body. *Medicine*, or the *Medical art*, endeavours to preſerve or to reſtore the health of animals, and is itſelf ſubdivided into other branches, &c.

Thus alſo with reſpect to the vegetable kingdom, the enumeration and regular arrangement of all the plants forms the ſcience of *Botany*. The art of cultivating them is called *Agriculture*, *Huſbandry*, &c.

In like manner with reſpect to minerals, the enumeration and arrangement of all their ſpecies, together with the deſcription of ſuch of their properties as are neceſſary to diſcriminate them from each other, forms the ſubject of *Mineralogy*. The conſideration of their original formation, and of their preſent natural diſpoſition in the body of the Earth, is denominated *Geology*. The particular knowledge and management of one ſort of minerals, viz. of metallic ſubſtances, is called *Metallurgy*; and ſo forth.

When the knowledge of thoſe various ſubjects was not very extenſive, all the known particulars could be eaſily arranged under the general title of Natural Philoſopy; but the progreſs of civilization, and the unremitted attention which has been beſtowed, particularly within the two laſt centuries, on ſcientific ſubjects, have increaſed the number of uſeful diſcoveries to ſuch a degree, as to render the capacity of one man inadequate to the comprehenſion of the whole ſtock of knowledge, and much leſs able to treat of all the above-mentioned ſubjects in a full and complete manner. Therefore, under the title of Elements of Natural Philoſophy, we mean to explain the principles,

principles, or the foundation of all thoſe various branches of knowledge, which depend upon the properties of natural bodies; whence the ſtudent may obtain a competent knowledge of the whole, and particularly of the admirable connexion which exiſts between them all, upon which, as upon a ſteady foundation, he may extend his knowledge of any particular branch, which his inclination or his profeſſion may lead him to adopt.

Almoſt all the bodies which come under the cognizance of our ſenſes, viz. all the animals, all the vegetables, and almoſt all the minerals, are compound bodies; viz. they evidently conſiſt of ſubſtances differing in weight, colour, and other properties, which may be ſeparated more or leſs eaſily from each other; but when ſeparated to a certain degree, the human art is not able to decompoſe them any farther. Now thoſe ſubſtances or components of animal, vegetable, and mineral bodies, which appear of a uniform nature, and which, at preſent, cannot be divided into more ſimple ſubſtances, muſt be reckoned elementary or primitive, until a mode of decompoſing them be diſcovered. Thus, for inſtance, water was formerly reckoned an elementary ſubſtance; but it has been of late years diſcovered, that it conſiſts of (for it may be reſolved into,) other ſubſtances, which poſſeſs properties very different from each other. Hence, at preſent, water is no longer looked upon as an elementary ſubſtance. It, therefore, naturally

turally appears that the number of elements muſt have been always fluctuating, and that it is likely to continue ſo for ages to come, ſince the ingenuity of man continually diſcovers new ſubſtances, and at the ſame time finds means of reducing into ſimple ſubſtances ſeveral ſuch bodies as had before paſſed for ſimple, primitive, or elementary.

The ſcientific perſons of the preſent time acknowledge the ſubſtances of the following liſt, as the elements or components of all animals, vegetables, and minerals; yet it will preſently be ſhewn that ſome of thoſe elements are merely hypothetical, and that they have been admitted as ſuch, by reaſoning from analogy upon other facts.

Elementary Substances:

Light
Calorific, or caloric
The Electric fluid
The Magnetic fluid
Oxygen
Hydrogen
Azote
Carbon
Sulphur
Phoſphorus
Radical muriatic
Radical boracic
Radical fluoric
Radical ſuccinic
Radical acetic
Radical tartaric
Radical pyro-tartaric
Radical oxalic
Radical gallic
Radical citric
Radical malic
Radical benzoic
Radical pyro-lignic
Radical pyro-mucic
Radical camphoric
Radical lactic

Radical

Radical ſach-lactic
Radical formic
Radical Pruſſic
Radical ſebacic
Radical bombic
Radical laccic
Radical ſuberic
Radical zoonic
Arſenic
Mollybdenite
Tungſten
Chrome
Titanite
Sylvanite
Uranite
Manganeſe
Nickel
Cobalt
Biſmuth
Antimony
Zinc
Iron
Tin
Lead
Copper
Mercury
Silver
Platina
Gold
Silica
Argill
Baryt
Strontian
Lime
Magneſia
Jargonia, or Zirgonia
Pot-aſh
Soda, and
Ammoniac

The firſt four of thoſe elements may with propriety be called hypothetical. Theſe are *Light*, or that fluid which renders objects perceivable by our eyes; *Caloric*, viz. the fluid which is ſuppoſed to produce the phenomena of heat, or to affect us with the ſenſation of heat; the *Electric Fluid*, which is ſuppoſed to produce the phenomena called *electrical*, and the *Magnetic Fluid*, to which the properties of the magnet are attributed; for, in in fact, the phenomena which fall under each of thoſe four denominations, are only ſuppoſed to be the effects of a ſingle fluid; reſpecting the nature of which, however, various opinions are entertained.

We ſhall treat at large of thoſe four very remarkable natural agents in the third part of this work; yet ſome of their properties muſt unavoidably be mentioned in treating of the properties of all the other elementary ſubſtances, in the preſent part.

With reſpect to the latter, it may likewiſe be obſerved, that ſome of them are only ſuppoſed to exiſt from analogy. Thus it is known that the ſulphuric acid conſiſts of ſulphur and oxygen; for it may be formed by combining thoſe two ſubſtances together, and it may be reduced into thoſe ſubſtances. It is likewiſe known, and for the like reaſon, that the carbonic acid conſiſts of carbon and oxygen; but the components of the muriatic acid are not known with certainty; yet from the analogy of other acids, the muriatic acid is ſuppoſed to conſiſt of oxygen joined to ſomething elſe, which ſomething elſe has been called the baſe of that acid, or the *muriatic radical.* The like obſervation may be applied to ſome other radicals.

The knowledge of the exiſtence of the abovementioned elementary ſubſtances, excepting the firſt four, has been acquired by the actual decompoſition of animal, vegetable, and mineral bodies, ſuch as are uſually found; and likewiſe by the actual

actual re-compoſition or formation of ſome bodies in a great meaſure ſimilar to the natural, from a combination of ſome of the elementary ſubſtances. The art of decompoſing natural bodies is called *Analyſis*;—the art of forming compounds is called *Syntheſis*; and both the art of analyſing, and the ſynthetical art, together with the knowledge of the principal facts which have been aſcertained by thoſe means, form the ſcience of *Chemiſtry*.

Having thus far given a general idea of all the bodies, which either are known to exiſt, or are, for very ſtrong reaſons, ſuppoſed to exiſt; I ſhall now ſubjoin a ſhort but comprehenſive view of their properties; and ſhall, at the ſame time, point out the order in which the particular deſcription of thoſe properties will be arranged in the following chapters.

It has been ſhewn in the firſt part of this work, that matter in general is poſſeſſed of *extenſion*, *diviſibility*, *impenetrability*, *mobility*, *vis inertiae*, and *gravitation*.—Upon the mobility and the *vis inertiae* of bodies, the extenſive doctrine of motion or the mechanical laws, have been eſtabliſhed; but that doctrine cannot be ſufficiently elucidated, unleſs it be particularly adapted to each of the three principal ſtates of bodies, viz. to ſolids, to non-elaſtic fluids, and to elaſtic fluids; therefore, having already explained the mechanical laws with reſpect to ſolids, it will be neceſſary, in the next place,

place, to treat of the mechanical properties of non-elaſtic fluids, under the title of *Hydroſtatics*; then of the mechanical properties of elaſtic fluids, under the title of *Pneumatics*; and laſtly, of the other peculiar properties, beſides the mechanical, which belong to each of them, viz. to ſolid and fluid, to ſimple and to compound, bodies, under the title of *Chemiſtry*.

The properties of bodies may be ſaid to be either of a *paſſive* or of an *active* nature. The former are *extenſion*, *figure*, *diviſibility*, *impenetrability*, *mobility*, *vis inertiae*, *denſity* and *rarity*, *hardneſs*, *ſoftneſs*, *fluidity*, *rigidity*, *flexibility*, *elaſticity*, *opacity*, and *tranſparency*; which have been ſufficiently defined in the preceding pages, and will be farther explained in the following; or their meaning is commonly too well known to require any particular definition. The latter, or thoſe of an active nature, are *attraction* and *repulſion*.

Beſides what relates to light, heat, electricity, and magnetiſm, there are four ſorts of attraction, viz. 1ſt. The attraction which every known body has towards all the reſt, and which is called *gravitation*; 2dly. The attraction which homogeneous parts of matter have towards each other, or by which they adhere to each other, and which is called the *attraction of aggregation*; and ſuch is the power by which two ſmall drops of quickſilver, when placed contiguous to each other, ruſh, as it were, into each other, and form a ſingle drop;

3dly. The *attraction* of *coheſion*, or that power by which the heterogeneous particles of bodies adhere to each other without any change of their natural properties; ſuch as the adheſion of water to glaſs, of oil to iron, &c. 4thly. The *attraction* of *compoſition* or of *affinity*, which is the tendency that parts of heterogeneous bodies have towards each other, by which they combine, and form a body, differing more or leſs from any of its components.*

Repulſion takes place either between the homogeneous, or between the heterogeneous, parts of bodies; but the exiſtence of the former is with great reaſon much doubted.

It is remarkable that of all thoſe properties we only know their exiſtence, and ſome of the laws under which they act; but we are otherwiſe utterly ignorant of their nature and dependence.

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* The inveſtigation and the knowledge of this laſt ſort of attraction, or affinity, is the moſt uſeful and extenſive, it being the foundation of chemiſtry and of various arts. Its inveſtigation is likewiſe very intricate, for it is different between any two bodies from what it is between any two others, and it fluctuates according to a vaſt variety of circumſtances. Thus, for inſtance, a certain body A has a greater tendency to mix with another body B in a particular temperature, than in any another. The ſame body A has a greater affinity to another body B, than to a third body C, and it may have no affinity at all, or even a repulſion, towards a fourth body D. Yet when D and C are mixed ſo as to form one compound body, then A may have an affinity to that compound.

CHAPTER II.

OF HYDROSTATICS.

HYDROSTATICS is the ſcience which treats of the preſſure and equilibrium of non-elaſtic fluids*; *Hydrodynamics* is the ſcience which treats of fluids in motion; and *Hydraulics* treats of the conſtruction of certain machines or engines in which fluids are principally concerned. But we ſhall now treat of what relates to non-elaſtic fluids, without taking any farther notice of thoſe nominal diſtinctions. †

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* This ſcience began to be cultivated by the great Archimedes.

† Water, oil, ſpirit of wine, and other ſuch fluids, are ſaid to be *non-elaſtic*, or *non-compreſſible*, not becauſe they are abſolutely ſo; but becauſe their compreſſibility is ſo very ſmall as to make no ſenſible difference in our calculations relative to the preſſures, movements, and other properties of thoſe fluids.

The ingenious Mr. Canton, in the year 1761, diſcovered the compreſſibility of water, of oil, &c. in the following manner. He took a glaſs tube having a ball at one end, much in the ſhape of a thermometer glaſs; filled the ball and part of the tube with water, which had been deprived of air as much

A *perfect fluid* is that whoſe parts may be moved from each other by the leaſt force. But ſuch a fluid is not to be found; for independent of its gravity, or weight, or tendency towards the centre of the earth, every non-elaſtic fluid is poſſeſſed of the

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much as it was poſſible; then placed it under the receiver of an air-pump, and on exhauſting the receiver, (viz. on removing the preſſure of the atmoſphere from over the water and the glaſs in which it was contained) the water roſe a little way into the tube, viz. expanded itſelf. And, on the contrary, when he placed the apparatus under the receiver of a condenſing engine, and by condenſing the air in the receiver, increaſed the preſſure upon the water, a diminution of bulk took place, for the water deſcended a little way into the tube. "In this manner," *he ſays*, "I have "found by repeated trials, when the heat of the air has been "about 50°, and the mercury at a mean height in the baro-"meter, that the water will expand and riſe in the tube by "removing the weight of the atmoſphere, one part in "21740; and will be as much compreſſed under the weight "of an additional atmoſphere. Therefore the compreſſion "of water by twice the weight of the atmoſphere is one "part in 10870."

"Water has the remarkable property of being more "compreſſible in winter than in ſummer, which is contrary "to what I have obſerved both in ſpirit of wine and oil of "olives."

Mr. Canton likewiſe ſubjected other fluids to the like experiments, and found them ſuſceptible of compreſſion and expanſion in the following proportions:

Compreſſion

the attraction of aggregation (viz. of the mutual attraction between its parts) in a particular degree; of the attraction of coheſion, which is likewiſe in a particular degree, towards other bodies, and of the attraction of affinity. Beſides which a ſort of obſtruction or want of perfect freedom may be obſerved more or leſs in all fluids. For inſtance, a ſmall drop of water placed upon a dry and clean glaſs plate, does not aſſume an horizontal ſurface, but remains nearly of a globular form; its attraction of aggregation, which draws every part of it towards its centre, being greater than its gravity; and its attraction of coheſion towards the glaſs being juſt ſufficient to let the drop adhere to the glaſs, when the latter is turned upſide down. But if the drop be ſpread over the ſurface of the glaſs, then the film of water will adhere to the glaſs with greater force, nor will it

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Compreſſion	of ſpirit of wine	66	millionth parts.
	of oil of olives -	48	
	of rain water - -	46	
	of ſea water - -	40	
	of mercury - - -	3	

Mr. Canton was of opinion that this ſmall degree of compreſſibility is not owing to the compreſſion of any air which might be lodged within thoſe fluids; for, having cauſed a quantity of water to imbibe more air than it contained in a preceding trial, he found that its compreſſibility was not thereby increaſed.—Canton's Papers in the Phil. Tranſ. vol. 52d and 54th.

recover its former globular form; becauſe by the ſpreading, its particles have been brought nearer to the glaſs, and the whole drop has been brought into contact with a much greater ſurface of the glaſs; by which means the attraction of coheſion, or attraction towards the glaſs, has been rendered much greater than the mutual attraction between the particles of water (for either of thoſe attractions is increaſed or diminiſhed by bringing the parts nearer to, or by removing them farther from each other), and it has likewiſe been rendered much greater than the attraction of gravitation.

If the ſame experiment be tried with a ſmall drop of quickſilver, inſtead of water, this alſo will aſſume a globular form, in conſequence of its attraction of aggregation; and it will adhere to the glaſs, if the latter be turned upſide down, on account of its attraction of coheſion. But it will be found impoſſible to ſpread it over the glaſs, becauſe its attraction of aggregation is much greater than its attraction of coheſion towards the glaſs.

When the quantity of fluid is conſiderable, as a cup nearly full of water, then the attraction of coheſion is much ſmaller than its gravitation, and the greateſt part of the fluid lies too far from the ſides of the cup, to be ſenſibly affected by its attraction. Hence the ſurface of the water, in conſequence of its gravitation, (as will preſently be ſhewn) will be horizontal, excepting that part of it which lies near the ſides of the cup, which will be attracted, and, aſcending a certain way, will drag part of the contiguous water in conſequence of its attraction of aggregation, ſo as to form a concave ſurface. On the other hand, by a little care, more water may be put in the cup than its abſolute capacity, or, ſpeaking more juſtly, the water may be made to project above the edge of the cup, and then near the edge it will aſſume a ſurface viſibly convex; it being prevented from falling over to a certain degree, by both the attraction of aggregation, and the attraction towards the ſides of the cup.

Thus much may be ſufficient to ſhew that both the quieſcent ſtate of fluids, and their movements, are influenced by a variety of powers: but as gravitation is the principal acting power, when the quantity of fluid is not very ſmall, we ſhall therefore proceed to ſtate and to explain the laws of hydroſtatics, upon the ſuppoſition that fluids are actuated only by the power of gravity; for we ſhall afterwards endeavour to point out the principal deviations from thoſe laws, which are occaſioned by the interference of other cauſes.

I ſhall however juſt mention, previouſly to the ſtatement of the neceſſary propoſitions, that though much mention is made of the *particles of fluids*, yet by this expreſſion we only mean indefinitely ſmall parcels of fluid; for we are not acquainted with the ſhape or ſize of thoſe particles, nor indeed with that diſpoſition which renders them ſo very moveable from each other. Our eyes, either naked or when aſſiſted by the moſt powerful microſcopes, cannot diſcover any component particles of any fluid. Some ſmall bodies are indeed to be ſeen in certain natural fluids, as in blood, milk, &c.; but thoſe are not the parts which conſtitute the fluid; they are ſolid or compact ſmall bodies, which ſwim in, or are mixed with the fluid.

Propoſition I. *Every body, or ſyſtem of bodies, endeavours to deſcend with its centre of gravity towards the centre of the earth, and that as near as it lies in its power.*

The truth of this propoſition is fully manifeſted by all that has been already ſaid relatively to the centre of gravity, and to the mechanical powers: but as it is the foundation of the doctrine of hydroſtatics, it will be of uſe to render it ſtill more familiar to the reader.

Thus if a ſolid body BD (fig. 1. Plate X.) be left at liberty, it will fall towards the ground, and if it happen to hit the ground with one end B firſt, in the oblique direction in which it is repreſented, it will not remain in the ſituation which is indicated by the dotted repreſentation, but it will fall flat upon the ground, as at BC; for in that ſtate its centre of gravity A will come as near as it poſſibly can to the ground, ſince the gravitating power will force the body to move on until a ſufficient impediment is interpoſed between the centre of the Earth and the centre of gravity of the body.

Now imagine that the abovementioned body be very ſoft, and it is plain that if the coheſion of its parts be leſs powerful than the gravity of thoſe particles, the body will not remain in the ſituation ABC, but will ſpread itſelf very flat and cloſe to the flat ſurface of the ground, in order that its centre of gravity may come as near as poſſible to the centre of the earth.

Farther, let the body AB, (fig. 2. Plate X.) conſiſting of two equal balls faſtened to an inflexible rod AB, be placed upon the fulcrum D, whilſt its centre of gravity is at C, viz. in the middle of the rod and it is evident that the end B will deſcend until the body remains in the ſituation of the dotted repreſentation EG; for in that caſe its centre of gravity C is as low as the obſtacles at D and G will permit it to deſcend.

The deſcent of this body AB may be prevented by applying a hand or ſome other obſtacle at F; but in this caſe the obſtacle at F will ſuffer a preſſure upwards, which preſſure is equal to the exceſs of the momentum of the end B above the momentum of the end A; viz. to the weight of B multiplied by BD, minus the weight of A multiplied by AD; for if that difference were added to the end A, the centre of gravity would then be removed from C to D, where it would be ſupported by the fulcrum D, and of courſe the two parts of the body on either ſide of D would balance each other; ſo that in this caſe one end of the body preſſes upwards, becauſe the greater momentum of the other end tends downwards; and the latter cannot act without producing the former.

Propoſition II. *A fluid which is kept in any veſſel open at top, will acquire, and will remain at reſt with, a flat ſurface parallel to the horizon, as long as it is not diſturbed.*

This is a natural conſequence of the preceding principle; for in that caſe the centre of gravity of the fluid will lie as low as it poſſibly can. Thus let ABDC (fig. 3. Plate X.) repreſent one ſide of a rectangular veſſel containing water as high as EF, whoſe centre of gravity is G; now we ſhall prove that when the ſurface of the water is flat and horizontal, as EF, then the centre of gravity of the water lies loweſt; but that if the water be elevated on any part of that ſurface, and of courſe lowered on any other part, then the centre of gravity will be removed to ſome place higher than G.

Imagine that the water be diſpoſed in the ſituation DKBC, viz. that the portion KEH be removed to the place BHF; and in this caſe the centre of gravity L of the quantity of water KDHFC remains in its original ſituation, whilſt the centre of gravity of the quantity of water KEH has been removed higher, viz. from I to S. Now ſince the common centre of gravity of two bodies is in a ſtraight line between the reſpective centres of gravity of thoſe bodies; therefore, the common centre of gravity of both the quantities of water formerly ſtood at G in the line IS; whereas it now ſtands at O in the line LS, viz. evidently higher than the level of G, which is the line *zr*.

This reaſoning, which has, for the ſake of brevity, been applied to one ſide of the veſſel, may be eaſily adapted to any ſection of the water and veſſel, as alſo to veſſels of any ſhape, and to any irregularity which the ſurface of the water may be ſuppoſed to acquire; for in any caſe the concluſion is exactly the ſame, namely, that the centre of gravity of a given quantity of ſome uniform fluid, like water, which is contained in an open veſſel of any ſhape, ſtands at the loweſt poſſible ſituation, when the whole ſurface of the fluid is in the ſame horizontal line.

It is an evident conſequence of this propoſition, that if *a veſſel conſiſt of two pipes perpendicular to the horizon, and open at top*, as in *fig*. 4. *Plate X*; *or if it conſiſt of various pipes communicating with each other, (howſoever they may be inclined to the horizon, but open at top), as in fig. 5. Plate X. and a quantity of water, or of other fluid, be poured into any of them, the water will riſe to the ſame horizontal line or level in all the pipes which communicate as above*; for in that caſe only the centre of gravity of the whole quantity of water will lie as low as the veſſel can admit of.

Thoſe perſons who may think it ſtrange that the fluid going down one pipe ſhould drive a part of the fluid upwards in the other pipe, muſt conſider

ſider that this is analogous to the preſſure upwards of the ſolid, fig. 2. Plate X. as explained in page 27; viz. the fluid is driven upwards in one pipe, in order that the greater quantity of fluid in the other pipe may deſcend lower down.*

Propo-

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* Though the application of prop. 2d. to the above-mentioned caſe of pipes, &c. be very obvious; yet to prevent any poſſible difficulty in the mind of the novice, I ſhall inſtance it in the caſe of fig. 4. by which example the attentive reader may be fully enabled to apply it to any other caſe.

GD and FC repreſent two equal cylindrical pipes open at top, communicating with each other at the bottom, and containing water as high as AB; the height AD, or BC, being 10 feet; it is evident that the centre of gravity of all the water which is contained in thoſe pipes muſt be at K, viz. five feet above DC, and midway between the two pipes; whilſt the centre of gravity of the water in each pipe is at Y and Z reſpectively. Now ſuppoſe it poſſible to remove two feet height of water from the pipe GD into the pipe FC; then, becauſe the pillar of water DE which remains in the pipe GD, is eight feet high, its centre of gravity muſt be at S, 4 feet above D; and becauſe the pillar of water CF in the other pipe now is 12 feet high, its centre of gravity T muſt be ſix feet above C; ſo that the centre of gravity of the water in GD has been lowered as much as the centre of gravity of the water in FC has been elevated; hence the ſtraight line ST muſt paſs through the point K, which is the common centre of gravity of both the pillars of water when they were equal.

But

Propoſition III. *The preſſure of the ſame fluid is in the proportion of its perpendicular height, and is exerted in every direction. So that all parts of the ſame fluid, at the ſame depth, preſs each other with equal force in every direction.*

In fig. 5. Plate X. it is evident that the quantities of water in the different pipes preſs equally againſt each other; for if a quantity of water be removed from any one of thoſe pipes, the ſurface of the water will deſcend to a lower level in all the other pipes; and that the preſſure is exerted equally in every direction is proved by obſerving that, however the pipes are connected at B, the water riſes to the ſame level in them all.

In order to prove that the preſſure is exactly proportional to the perpendicular height of the water, let ABE, GHD, be (fig. 6. Plate X.) two cylindrical pipes of equal diameter, ſituated perpendicular to the horizon; and let them contain equal quantities of water, which of courſe muſt be

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But now the quantity of water CF is to the quantity of water ED, as 12 to 8, or as 3 to 2; therefore (ſee p. 75. Vol. I.) the diſtance of their common centre of gravity O from S, muſt be to its diſtance from T, as 3 to 2, viz. it muſt be nearer to T than to S, or nearer to T than the point K is; for K is midway between S and T; therefore, by removing part of the water from one pipe to the other, the centre of gravity of the whole has been raiſed; hence that centre of gravity lies loweſt when the ſurface of the water in both pipes is in the ſame level, or horizontal line, AB.

equally high in both pipes, viz. AB equal to CD; and the preſſures on the bottoms BE, ED muſt evidently be equal. Now let the water AFBE be poured into the other pipe, where it will occupy the ſpace GHFC, ſo as to make the whole perpendicular height HD double the height CD. And it is alſo evident that the quantity of water GHFC muſt preſs as much upon the ſurface of the water FCED, as it did upon the bottom BE; therefore the preſſure on the bottom ED is now double of what it was before, viz. a double perpendicular height occaſions a double preſſure. In the ſame manner it is proved that a treble perpendicular height occaſions a treble preſſure; or, univerſally, that the preſſure is as the perpendicular height. And the ſame thing is evidently true with reſpect to any other uniform fluid.

Notwithſtanding the evidence of this demonſtration, ſome of my readers may ſtill wonder that a ſmall quantity of water, ſuch as is contained in the pipe AB, (fig. 7. Plate X.) ſhould balance the large quantity of water in the pipe DC; and to thoſe it may be of uſe to ſee this property exhibited in another light.

Suppoſe then that the capacity of the cylindrical veſſel EDC be equal to 100 times the capacity of the other cylindrical veſſel AFB. Now if the water were to riſe one inch above ED in the large veſſel, it is evident that it would neceſſarily fall 100 inches below AF in the ſmall veſſel; ſo that

that the ſpaces, through which thoſe two quantities of water move, or their velocities, are inverſely as their quantities, or their weights: hence their momentums are equal, and of courſe they balance each other, in the ſame manner as the two weights R and Z of fig. 8. Plate X. balance each other, when the arms of the rod on either ſide of the prop S are inverſely as the weights.

It is an evident conſequence of this propoſition, *that the preſſure on any determined part of the bottom, or of the ſides, of any veſſel containing a uniform fluid, like water, is equal to the weight of a pillar of that fluid having a baſe equal to that part of the bottom, or ſide, and the altitude equal to the perpendicular height of the fluid above it.*

Whence we may calculate the preſſures upon, and of courſe the ſtrength required for, dams, pens, ciſterns, aqueducts, dikes, flood-gates, &c. (1.) Before

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(1.) The practical application of this corollary to ſuch ſurfaces as are parallel to the upper ſurface of the fluid, is eaſy and obvious; for we need only multiply the given ſurface by the perpendicular altitude of the fluid above it. Thus if it be required to determine the preſſure upon two ſquare feet of the flat bottom of a veſſel which contains three feet perpendicular depth of water, we multiply 2 feet by 3, and the product is 6; viz. the propoſed part of the bottom ſuſtains a preſſure equal to the weight of ſix cubic feet of water; but one cubic foot of water weighs about 1000 avoirdupoiſe

Before we proceed any farther, it is neceſſary to obſerve, that the ſurface of the water, or of any other fluid, has been ſaid to aſſume a flat horizontal ſurface, or to come to the ſame horizontal line, in

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dupoiſe ounces; therefore the above-mentioned preſſure is equal to 6000 ounces, or to 375 pounds.

But the application of it to oblique or curve ſurfaces is not equally obvious; for every point of ſuch ſurfaces is at a different diſtance from the upper ſurface of the fluid: we ſhall, therefore, endeavour to elucidate it in a more particular manner; and for this purpoſe it will be neceſſary to premiſe the following propoſition, which is demonſtrated in an eaſy and perſpicuous manner, as given by Mr. Cotes in his Hydroſtatical Lectures.

If any indefinitely ſmall part or point of a ſurface, or number of ſurfaces, be multiplied by its perpendicular diſtance from any given plane; the ſum of the products will be equal to the product of the whole ſurface, or number of ſurfaces, multiplied by the perpendicular diſtance of the centre of gravity of the ſingle ſurface, or of the common centre of gravity of the whole number of ſurfaces, from the ſame plane.

In fig. 17. Plate X. let any number of quantities a, b, c, d, repreſent as many weights, hanging at their centres of gravity, a, b, c, d, by the lines ao, bo, co, do, fixed to any horizontal plane o, o, o, o; and let z be the common centre of gravity of all the weights, and zo its perpendicular diſtance from that plane: I ſay that $a \times ao + b \times bo + c \times co + d \times do = \overline{a+b+c+d} \times zo$.

For let the common centre of gravity of the weights a, b, be the point x, and to the line xo, drawn parallel to the reſt, in ſuch pipes as communicate together, on the ſuppoſition that the force of gravity acts in the direction of parallel lines; and ſuch appears to be the caſe with ſmall ſurfaces of water, as for inſtance,

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reſt, let *am* and *bn* be perpendiculars. Then by the ſimilar triangles *mxa*, *nxb*, we have $mx : nx :: (xa : xb ::)\ b : a$, by the known property of a centre of gravity. Hence $a \times mx = b \times nx$, or $a \times \overline{mo - xo} = b \times \overline{xo - no}$, or, $a \times mo - a \times xo = b \times xo - b \times no$: whence $a \times mo + b \times no = \overline{a+b} \times xo$; which was to be proved in the ſimpleſt caſe of the propoſition.

Now let a weight $x = a + b$, be ſuſpended by a line *xo*, in the common centre of gravity of *a* and *b*; and likewiſe a weight $y = x + c$, in the common centre of gravity of *x* and *c*; and alſo a weight $z = y + d$ in the common centre of gravity of *y* and *d*: Then *z* is the common centre of gravity of all the weights *a*, *b*, *c*, *d*, firſt propoſed.

Conſequently, by what has been proved in the firſt caſe, we have $a \times ao + b \times bo = x \times xo$; and likewiſe $x \times xo + c \times co = y \times yo$; and likewiſe $y \times yo + d \times do = z \times zo$: conſequently, $a \times ao + b \times bo + c \times co = y \times yo$; and likewiſe $a \times ao + b \times bo + c \times co + d \times do = (z \times zo =)\ \overline{a+b+c+d} \times zo$; which was to be proved.

Hence if a ſurface or number of ſurfaces of any kind be conſidered as equally ponderous in every equal part, and as divided into indefinitely ſmall parts, ſuſpended by lines drawn from their centres perpendicularly to any horizontal plane; it is manifeſt that if every part be multiplied reſpectively into its perpendicular line, the ſum of the products will be equal to the product of the whole ſurface multiplied ſtance, a ſmall pond, a ciſtern, &c. But ſince the force of gravity tends to the centre of the Earth, every point of the ſurface of the water, or of any other fluid, when quieſcent, muſt be equidiſtant from that

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into the perpendicular diſtance of its centre of gravity from the ſaid plane; and that this equality of the products will ſubſiſt even if the ſaid lines be perpendicular to any plane, though not parallel to the horizon.

This being premiſed, the method of determining the preſſure of a fluid upon any given ſurface becomes evident and general; for conſidering the upper ſurface of the fluid as the above-mentioned plane, in the firſt place we find the area of the given ſurface (by common menſuration); ſecondly, we find the centre of gravity of the ſame (by the rules of chap. VI. P. I.): then multiply the area of the given ſurface by the perpendicular diſtance of its centre of gravity from the ſurface of the fluid, and the product will expreſs the preſſure. Thus the preſſure on the ſurface of an hemiſpherical veſſel full of water, is equal to the product of its ſurface multiplied by its radius.

Thus alſo the preſſure upon the ſide ABCD of the rectangular veſſel, fig. 18. Plate X.; full of water, is equal to the product of the area ABCD multiplied by half the depth of the water; viz. by the diſtance of the centre of gravity E of the propoſed ſurface from the ſurface of the water.

It appears from what has been ſaid above, that the preſſure of a ſuperincumbent fluid on the ſide of a veſſel, or, in general, on any ſurface which is not parallel to the ſurface of the fluid, muſt be unequally diſtributed over it. Thus, for inſtance, if through the centre of gravity E of the ſide ABCD, that centre: hence that fluid muſt aſſume a ſpheroidical ſurface, like that of the Earth; and this curvature is both viſible and meaſurable in large ſurfaces of water, as that of the ſea.

Since

ABCD, fig. 18. Plate X, an horizontal line be drawn, which divides that ſide into two equal parts; it is evident that the preſſure on the lower half is greater than the preſſure on the upper half, becauſe the former lies deeper into the water. Therefore there muſt be an horizontal line lower than the middle E, which divides the ſide ABCD into two ſuch unequal parts, as that the preſſure of the fluid upon one of thoſe parts be equal to the preſſure of the fluid upon the other. Hence if the whole preſſure of the fluid were collected upon that line, it would have the ſame effect upon the plane, as when it was diſtributed unequally upon it.

It may be likewiſe eaſily conceived, that in the laſt mentioned line there muſt be a point, in which if the whole preſſure were collected, it would have the ſame effect upon the plane as when the preſſure was unequally diſtributed all over it.

It follows, that if exactly againſt that point, but on the oppoſite ſide of the plane, a force be applied equal to the whole preſſure of the fluid upon that plane, this force would exactly counteract that preſſure, and the plane would remain perfectly at reſt, viz. it would not incline to any ſide. Now that point in any ſurface is called *the centre of preſſure of that ſurface*, and may be inveſtigated by means of a fluxionary calculation. But for this inveſtigation, which goes rather beyond the limits of an elementary treatiſe, I muſt refer my inquiſitive

Since fluids preſs in every direction, and that preſſure is as their perpendicular heights; therefore, at the ſame depth, the particles of the fluid preſs equally againſt each other. Alſo, ſince equal bulks of a uniform fluid are of equal weight, therefore no motion can take place in a fluid without ſome external cauſe; but if one parcel of the fluid becomes lighter or heavier than the reſt, then that portion will aſcend or deſcend in the fluid, giving way to other parcels of the fluid that are heavier or lighter than itſelf.

When the bottom, or one ſide of a veſſel full of fluid

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inquiſitive readers to the works of other writers. It is neceſſary however to add the following obſervations.

In this caſe the plane, which ſuſtains the preſſure of the fluid, is ſuppoſed to be an inflexible plane, or the ſurface of a very ſubſtantial ſolid; for if the plane be the thin ſide of a veſſel, or any other very flexible ſubſtance, the preſſure collected in one point would not produce the ſame effect as when it is diſtributed over the whole plane. It may be ſuſtained in the latter caſe, whereas it might bend or burſt the plane in the former.

Various writers have concluded, that if a plane immerſed in a fluid be ſuppoſed to be extended until it cuts the ſurface of the fluid, and if that ſection be conſidered as the axis of motion of a pendulum whoſe bob, or ſuſpended body, is the propoſed plane; the centre of oſcillation of ſuch a pendulum coincides with the centre of preſſure of that plane. But Profeſſor Vince ſhews, in his principles of hydroſtatics, Sect. I. Prop. XII. that thoſe points ſeldom coincide.

fluid is heated, the fluid which is contiguous to the heat, is thereby rarefied, viz. its bulk becomes enlarged, and of courſe it becomes lighter than an equal bulk of the ſame fluid which is not ſo rarefied; hence it aſcends in it, &c.—And this is the cauſe of the motion which takes place in fluids that are heating or boiling.

The ſame thing which has been ſaid of fluids in fluids, or of the parcels of a fluid, is applicable to ſolids, viz. a ſolid at any depth is preſſed in proportion to the perpendicular altitude of the fluid over it; but as that preſſure acts on every ſide, the body will not aſcend nor deſcend in the fluid, unleſs its weight is ſmaller or greater than that of an equal bulk of the ſurrounding fluid.

If the immerſed body be compreſſible, ſuch as a bladder full of air, then the preſſure of the ſuperincumbent fluid, according to its perpendicular height, will be rendered manifeſt; for the deeper the body is conveyed, the more will its bulk be contracted.*

If

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* Sailors at ſea frequently ſhew the following experiment: They cork an empty bottle, (viz. a bottle full of air), tie it to a rope, to which is added a leaden weight, and let the whole down into the ſea to a certain depth; they then pull up the apparatus, and generally find that either the cork is driven into the bottle, or the bottle is broken. But if the experiment be tried with a bottle full of water, or of wine, and corked as before, no alteration will

If, when a ſolid is immerſed in a fluid, the preſſure of the fluid on one ſide of the body be prevented, then the preſſure on the other ſides of it will be rendered manifeſt; and by this means a body actually heavier than an equal bulk of water, may be cauſed to be preſſed upwards by the water; and, on the other hand, a body actually lighter than an equal bulk of water may be cauſed to be preſſed downwards by the water.

Take a glaſs tube about 18 inches long, as AB fig. 20. Plate X. open at both ends, and let its lower end be ground quite flat and ſmooth. Let a braſs plate C, a little larger than the diameter of the tube, be ground likewiſe very flat, and fix a little hook to its middle, to which a ſtring D *o* muſt be tied. Place the braſs plate againſt the aperture of the tube, and by pulling the ſtring at D, keep the

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will take place. This difference of effect is owing to the bottle being full of a compreſſible fluid in the former caſe, and of a non-compreſſible fluid in the latter.

At the depth of 32 feet below the ſurface of the ſea, a diver has been calculated to be preſſed with the weight of about 28000 avoirdupoiſe pounds; yet as that preſſure is diſtributed all over his body, and the human body conſiſts moſtly of non-elaſtic fluids or of ſolids, he does not feel any remarkable inconvenience from it.—This preſſure is calculated in the following manner.

The ſurface of the body of a middle ſized man is reckoned equal to about 14 ſquare feet; therefore a diver ſituated 32 feet the plate tight againſt the tube. In this ſituation immerge the tube in the water, until the plate is below the ſurface to the depth of more than 8 or 10 times its thickneſs. Then if the ſtring be let go, the plate will not fall off, but will remain adhering to the glaſs tube; the reaſon of which is, that now the water preſſes only againſt the under part of the braſs plate. And, in fact, if water be poured into the tube, then the plate will be immediately ſeparated from the tube, and will fall to the bottom of the veſſel EF.

A braſs plate *ac*, fig. 21. Plate X. very flat and ſmooth, muſt be cemented to the bottom of a veſſel EF; a ſimilar ſmooth braſs plate, to which a large cork is cemented ſo as to form a compound body lighter than an equal bulk of water, muſt be laid upon the former plate, and in very cloſe contact with it.

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feet below the ſurface of the ſea is preſſed by a pillar of water whoſe baſe is 14 ſquare feet, and altitude 32 feet. Now ſuch a pillar contains (14 × 32 =) 448 cubic feet of water, and as a cubic foot of water weighs about 1000 avoirdupoiſe ounces; therefore the weight of ſuch a pillar is (448 × 1000 =) 448000 ounces, or 28000 avoirdupoiſe pounds.

In this calculation the ſurface of the body of the diver has been conſidered as being all at an equal diſtance from the ſurface of the ſea, which is not really the caſe: but at the depth of 32 feet the difference of perpendicular diſtance of the various parts of the body is not conſiderable; ſo that the reſult of the calculation is very near the truth, eſpecially if the depth be reckoned from the middle of the body.

it. Then by applying a hand, or a ſtick to the upper part of the cork, keep it down until the veſſel EF be filled with water. This done, remove the hand or ſtick from over the cork, and it will be found that, though ſpecifically lighter than water, the cork and braſs plate will not aſcend to the ſurface of the water. The reaſon of which is, that the water cannot in this caſe preſs on the lower ſurface of that braſs plate. And in fact, if by means of the ſtick or hand, the upper braſs plate be ſeparated a little from the lower one, ſo that the water may enter between them, then the upper plate with the cork will immediately aſcend to the ſurface of the water.

Propoſition IV. *When fluids of different ſpecific gravities mutually preſs againſt each other, their ſurfaces cannot lie in the ſame level; but their perpendicular altitudes above the level of their junction are inverſely as their ſpecific gravities.*

The weights of equal bulks of different bodies are called *their ſpecific gravities*, or *their relative* weights. Thus, for inſtance, if you fill a veſſel with water, and weigh it; then remove the water, fill it equally full with quickſilver and weigh it again, you will find it to weigh in the latter caſe 14 times as much as it weighed in the former*: therefore the ſpecific gravity of quickſilver is ſaid to

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* 14 is rather greater than the truth. The real weight will be ſhewn hereafter.

be 14, whilſt the ſpecific gravity of water is ſaid to be one; and ſo of the reſt. Hence the weights of bodies, or their *abſolute weights*, are expreſſed by the products of their bulks multiplied by their reſpective ſpecific gravities; for, in the above-mentioned inſtance, if the weight of quickſilver is 14 pounds, when that of an equal bulk of water is one pound, it follows that 4 times that bulk of quickſilver muſt weigh 4 times 14, or 56 pounds; that 10 times that bulk of quickſilver muſt weigh 140 pounds; that twice that bulk of water muſt weigh twice one, viz. 2 pounds; and ſo forth.

Now let the part ECDF of the cylindrical bent tube, fig. 9. Plate X. be filled with quickſilver, the ſurface of which will come to the ſame level EF in both legs. Then ſuppoſe that one inch height of quickſilver, viz. GE, be removed from the pipe CS, and that inſtead of it fourteen inches of water, viz. GS, be added; it is evident that ſince quickſilver is fourteen times as heavy as water, the perpendicular pillar of water GS muſt preſs upon the ſurface of the quickſilver GV, as much as the perpendicular pillar of quickſilver EG: hence the preſſure againſt the quickſilver in the pipe BD remaining the ſame, its ſurface muſt remain at F. But the ſurface of the water is at S, viz. 14 inches above the level GZ of the junction of the two fluids, whilſt the ſurface F of the quickſilver is one inch above the ſaid level. Therefore the perpendicular heights of thoſe fluids above the

the level of their junction are inverſely as their ſpecific gravities.—The like reaſoning may evidently be applied to all other fluids, and to veſſels of any other ſhape: therefore the propoſition is univerſally true.

Propoſition V. *A body floating in a fluid diſplaces a quantity of the fluid, the weight of which is equal to the weight of the body.*

Thus the body DB, fig. 10. Pl. X. floating on the fluid FHG, weighs as much as the quantity of that fluid which would exactly fill up the ſpace ABCE; for the body DB is kept in that place by the preſſure of the ſurrounding water, which ſame preſſure, previouſly to the immerſion of the body, was juſt ſufficient to keep in the ſame place a quantity of the ſame fluid equal to the ſpace ABCE: therefore the weight of that quantity of the fluid is equal to the weight of the body.

The following conſequences, or *corollaries*, are naturally deduced from this propoſition.

1. If the ſame body be ſucceſſively placed on fluids of different ſpecific gravities, it will diſplace different quantities of thoſe fluids; that is, it will ſink deeper in the lighter than in the heavier fluid.

2. If the weight of the body be equal to that of an equal bulk of the fluid, then that body will remain at reſt in any part of that fluid below the ſurface,

ſurface, and no part of the body will appear above the ſurface of the fluid.

3. If a body heavier than an equal bulk of a certain fluid, be placed on the ſurface of that fluid, it will ſink with the exceſs of weight by which the weight of the body exceeds the weight of an equal bulk of the fluid. Thus, if a body which weighs three pounds be put in water, and a quantity of water equal in bulk to that body weighs two pounds; then the body will deſcend in the water with the force of one pound; the meaning of which is, that if that body be tied by means of a ſtring to one ſcale of a balance, and be weighed, firſt out of the water, and then in water, as in fig. 11. Pl. X. it will be found to weigh three pounds out of the water, and one pound in water: whence it follows, that if the weight of a body be divided by that weight which it loſes in water, the quotient ſhews its ſpecific gravity; viz. it ſhews how many times that body, is heavier than an equal bulk of water.

4. If a body lighter than an equal bulk of a certain fluid be placed at the bottom of a veſſel full of that fluid, that body will aſcend with more or leſs force, according as the difference of weight between the body and an equal bulk of the fluid is greater or ſmaller; becauſe a quantity of the fluid equal to it in bulk, but heavier than the body, will continully take its place, until part of the body projects above the ſurface of the fluid; and

and only ſuch a part of it will remain in the fluid, as can diſplace a quantity of the fluid whoſe weight equals the weight of the body. Therefore in order to keep that body below the ſurface of the fluid, you muſt preſs it with a weight equal to the difference between the weight of the body and the weight of an equal bulk of the fluid.

5. If a body be cauſed to float ſucceſſively on two different fluids, the quantities of thoſe fluids, which are diſplaced by that body, and likewiſe the parts of that body which are immerſed in the two fluids, will be inverſely as the ſpecific gravities of thoſe fluids. Thus, ſuppoſe that a ſolid body weighs 5 lbs. that an equal bulk of water weighs 10 lbs. and that an equal bulk of another fluid weighs 15 lbs. in which caſe the ſpecific gravities of the ſolid body, of the water, and of the other fluid, are as 1, 2, and 3: Then that body, when floating upon water, will diſplace a quantity of water which is equal to one half of its bulk, and when floating upon the other fluid, it will diſplace a quantity of that other fluid, which is equal to one third part of its bulk. But one half is to one third, as 3 is to 2, and thoſe numbers are inverſely as the ſpecific gravities of water and of the other fluid.

6. When a ſolid is floating upon a fluid, the part immerſed is to the whole ſolid, as the ſpecific gravity of the ſolid is to the ſpecific gravity of the fluid; for when the ſpecific gravity of the ſolid is

equal to that of the fluid, then the ſolid diſplaces a quantity of fluid equal in bulk to itſelf; when the ſpecific gravity of the ſolid is the half of that of the fluid, then it diſplaces a quantity of fluid the bulk of which is equal to the half of its own bulk; and ſo forth.

7. All bodies retain their whole gravity when immerſed in a fluid; but that gravity is either partly or entirely counteracted by the preſſure of the fluid, according as the gravity of the immerſed body is equal to, or different from, that of an equal bulk of the fluid.

Propoſition VI. *If a lighter fluid reſt upon a heavier, and a body whoſe ſpecific gravity is greater than that of the upper, and leſs than that of the lower fluid, remain between them; the part of it which ſtands in the upper fluid is to the part of it which ſtands in the lower fluid, as the difference between the ſpecific gravity of the lower fluid and the ſpecific gravity of the body, is to the difference between the ſpecific gravity of the upper fluid and the ſpecific gravity of the body.*

The demonſtrations of this and of the following propoſitions will be found in the notes; ſo that the reader may, according to his capacity, either examine them, or take the propoſitions for granted. (2.)

(2.) Fig. 12. Plate X. repreſents a veſſel which contains two fluids, whereof ADEF is the lighter, whoſe ſpecific gravity

Cor. *The part L is to the whole body, as the difference between the ſpecific gravities of the ſolid and lighter fluid, is to the difference between the ſpecific gravities of the heavier and lighter fluids.* (3.)

Propoſition

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vity is a; EFG the heavier, whoſe ſpecific gravity is b: UL is the body, whoſe ſpecific gravity is c, and which remains with the part U in the upper, and with the part L in the lower, fluid.

It has been ſhewn in cor. 3. of prop. V. that if the weight of a body be divided by the weight which it loſes in a fluid (which is the weight of an equal bulk of that fluid) the quotient will expreſs the ſpecific gravity of that body in compariſon with that of the fluid, which will be called unity. Therefore if the weight of the body out of the fluid be divided by its ſpecific gravity, the quotient will be the weight of a quantity of that fluid equal in bulk to the body. Hence it appears that the weight of the body is $c \times \overline{U+L}$, that the weight of that quantity of the lower fluid which is diſplaced by the part L, is Lb, and the weight of that quantity of the upper fluid which is diſplaced by the part U, is Ua: therefore $Lb + Ua = c \times \overline{U+L} = Uc + Lc$. Hence $Lb - Lc = Uc - Ua$; or $L \times \overline{b-c} = U \times \overline{c-a}$: therefore $U : L :: b-c : c-a$.

(3.) The laſt analogy, by inverſion and compoſition, becomes $L : L+U :: c-a : b-a$.

Conſidering that we are ſurrounded by a thin and inviſible fluid called *air*, (as will be more particularly ſhewn in the ſequel) in which we conſtantly move and live; it follows that a body when weighed in the common way, that is, in air, weighs leſs than if it were weighed in vacuo, viz.

Propoſition VII. *If two fluids be mixed together, the bulk of the heavier fluid is to the bulk of the lighter, as the difference between the ſpecific gravities of the mixture and of the lighter fluid, is to the difference between the ſpecific gravities of the mix-*

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viz. where there is no air; "alſo, that if any ſubſtance "float upon the ſurface of a fluid in vacuo, upon admitting the air, the floating body will riſe higher above the "ſurface, ſo that the proportion of the part immerſed to "the whole will be ſomewhat leſs than before. The dif- "ference of the parts of a ſolid immerſed in a fluid, when "in vacuo, and in open air, may be eſtimated in general "thus." — *Atwood's Deſcrip. of Experiments for a Courſe of Lectures.*

Let m = the magnitude of the ſolid body;
s = its ſpecific gravity;
A = the part immerſed when in open air;
B = the part immerſed when in vacuo;
a = the ſpecific gravity of the fluid in which the ſolid is immerſed;
g = the ſpecific gravity of air.

Then (Cor. 6. of Prop. V.) $B : m :: s : a$; and $B = \frac{ms}{a}$ = to the part immerſed in the fluid when no air is over it.

By the corollary to the laſt Prop. $A : m :: s - g : a - g$; and $A = m \times \frac{s - g}{a - g}$ = to the part immerſed in the fluid when the air is over it, as in the common way. And the difference of thoſe parts $= B - A = \frac{ms}{a} - \frac{m \times \overline{s - g}}{a - g} = \frac{m \times \overline{sa - sg - sa + ag}}{a^2 - ag} = \frac{mg \times \overline{a - s}}{a^2}$ nearly.

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ture and of the heavier fluid. Then as the bulk of the heavier fluid, multiplied by its ſpecific gravity, is to the bulk of the lighter fluid multiplied by its ſpecific gravity, ſo is the weight of the heavier fluid to the weight of the lighter fluid (3).

The ſame thing muſt be underſtood of two

The ſpecific gravity of air (viz. g) is about 0,0013; hence, by making the computation, it will appear that the exiſtence of the air over a fluid in which a ſolid floats, produces a very ſmall difference with reſpect to the part of the ſolid which is immerſed in the fluid; ſo that it needs not be regarded, unleſs the utmoſt preciſion be required; in which caſe the actual ſpecific gravity of the air, as indicated by the barometer, muſt be taken into the computation; for the gravity of the air is continually varying, and its actual quantity is ſhewn by the barometer, as will be explained hereafter.

It follows likewiſe, that if two bodies, of different ſpecific gravities, balance each other in a pair of ſcales, their weights are not exactly equal; for if the air were removed, that body whoſe ſpecific gravity is leaſt would preponderate.

(3.) Let A and B repreſent the bulks of the two fluids, a and b their ſpecific gravities, and c the ſpecific gravity of the compound. Then the weight of the compound is repreſented by $c \times \overline{A+B}$; the weight of A is repreſented by A a, and the weight of B is repreſented by B b; therefore $Ac + Bc = Aa + Bb$; and $Bc - Bb = Aa - Ac$; that is, $\overline{c-b} \times B = \overline{a-c} \times A$; conſequently $A : B :: c-b : a-c$.

ſolids intermixed together, ſuch as an alloy of two different metals, &c.

This propoſition is, however, true only when the bulk of the compound is equal to the ſum of the bulks of the two components previouſly to their being mixed, which ſeldom is the caſe; experience ſhewing (as will be particularly mentioned in the ſequel) that when two or more bodies are mixed together, a ſort of incorporation, and ſometimes an expanſion, frequently takes place, which is attended with a diminution or increaſe of bulk; thus, a pint of ſpirit of wine mixed with a pint of water, forms a compound which meaſures leſs than two pints. And a cubic inch of tin incorporated, by means of fuſion, with a cubic inch of lead, will form a maſs which meaſures more than two cubic inches.

When ſuch increaſe or decreaſe of bulk does not take place, then we may, by the laſt propoſition, find out the weights of two ingredients which form a compound body, having given the ſpecific gravities of the ingredients, and of the compound.

CHAPTER III.

OF THE SPECIFIC GRAVITIES OF BODIES.

IT has been already mentioned that the ſpecific gravity of a body is the proportion which its weight bears to the weight of another body of equal bulk. Thus the ſpecific gravity of mercury is ſaid to be to the ſpecific gravity of water as 14 to one; the meaning of which is, that if a quantity of mercury, which exactly fills a certain veſſel, and a quantity of water which likewiſe exactly fills the ſame veſſel, be weighed ſeparately, the former will be found to weigh 14 times as much as the latter; ſo that if the water weighs one pound, or one ounce, &c. the mercury will be found to weigh 14 pounds, or 14 ounces, &c.— Thus alſo the ſpecific gravity of mercury is to the ſpecific gravity of zinc as two to one; viz. if a a cubic inch, or a certain veſſel full, of mercury weigh 14 pounds, a cubic inch, or the ſame veſſel full, of zinc will be found to weigh 7 pounds. Or if the former weigh 100 grains, the latter will be found to weigh 50 grains; and ſo on.

But though bodies may be thus compared indiſcriminately together, yet conveniency has eſtabliſhed the cuſtom of comparing all bodies with water, the ſpecific gravity of which is reckoned one,

one, or unity; ſo that, ſpeaking of the above-mentioned bodies, the ſpecific gravity of mercury is ſaid to be 14, and that of zinc, to be 7; meaning that equal quantities of water, of mercury, and of zinc, weigh reſpectively 1, 14, and 7, be they pounds, or ounces, or grains, or any other weights. Nor does this mode of expreſſing the ſpecific gravities alter the proportion between any two or more bodies; for inſtance, it has been ſaid above that the ſpecific gravity of mercury is to that of zinc as two to one, and by the laſt expreſſion thoſe ſpecific gravities have been ſtated as 14 and 7; but thoſe two numbers are to each other exactly in the ratio of two to one.

The reaſons for which water has been generally adopted as the ſtandard with which all other bodies are compared, are, 1ſt, that by weighing the ſame body out of water and in water, the ſpecific gravity of that body may, in general, be more eaſily aſcertained than by any other means; and 2dly, that water of the ſame purity and of the ſame ſpecific gravity, may be eaſily procured in every country.

But the ſpecific gravity of water is liable to be altered by two cauſes, viz. by the admixture of other ſubſtances, and by an alteration of temperature; — water, for inſtance, at 100° of temperature, is lighter than water at 60°; and ſtill lighter than water at 40°. Therefore the water, which is to be uſed for the purpoſe of aſcertaining the ſpecific gravities of bodies, muſt be free from heterogeneous ſubſtances, and muſt be uſed always at the ſame degree of temperature.

Diſtilled water, and rain water, are ſufficiently pure, and equally uſeful for the above-mentioned purpoſe, as they have not been found to differ in ſpecific gravity.

The moſt natural way of determining the ſpecific gravity of bodies is to weigh in a pair of ſcales, or by means of a ſteelyard, bodies of different ſorts, but of preciſely the ſame dimenſions; and this, indeed, is a very good practical method for fluids, which may be put ſucceſſively into the ſame phial, &c.; but the difficulty of forming ſolids exactly of the ſame dimenſions is ſo very great, that their ſpecific gravities are generally determined by weighing each body both out of water and in water, in the manner which will be particularly deſcribed in this chapter; excepting ſome powdery ſubſtances, which, in this reſpect, may be treated like fluids.

It appears, therefore, that a common pair of ſcales, or balance, is the principal inſtrument which is required for determining the ſpecific gravities of bodies. It only requires to have a hook affixed under one of the ſcales. This balance, when in uſe, might be held in the operator's hand: but as thoſe experiments require a certain time, and much accuracy, therefore it is adviſable to have them ſet upon a ſtand, ſuch as is repreſented in fig.

fig. 14. of Plate X. The whole apparatus, then, for determining ſpecific gravities, which goes under the name of the *Hydroſtatical Balance* and its *apparatus*, conſiſts of the following parts. A balance, ſuch as ABCD, fig. 14. Plate X. which ſhould be ſo ſenſible as to turn at leaſt with the 20th part of a grain when each ſcale is loaded with a weight of two or three ounces. An accurate ſet of weights, eſpecially of grains, ſuch as weights of 10 grains and of 100 grains, beſides the ſingle grains; it being much more commodious to make the computation entirely in grains, or at moſt in ounces and grains, than to be encumbered with weights of different denominations. A glaſs jar E, about 7 or 8 inches high, which is to contain the diſtilled or rain-water. A glaſs ball, of about an inch, or an inch and a half in diameter, with a bit of fine platina wire, about three inches long, affixed to it*. A ſmall glaſs bucket G, with

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* This ball may be either of ſolid glaſs, or of hollow glaſs partly filled with quickſilver, or with ſome other heavy ſubſtance. In the latter caſe it generally has a ſhort perforated ſtem, into the perforation of which the platina wire is faſtened with cement. But if it be a ſolid glaſs ball, a hole of about $\frac{1}{5}$th of an inch in length muſt be drilled in it, wherein the wire is to be faſtened. For the ſake of expedition in making the computation, it would be proper to make this glaſs ball of a certain weight expreſſible by a round number; for inſtance, of 100, or 500, or 1000 grains.

a glaſs handle. A ſmall phial or two, as H; viz. of ſuch a ſhape as to admit of their being eaſily filled, emptied, and cleaned. And a thermometer I.

This hydroſtatical balance and apparatus is commonly made by the philoſophical inſtrument-makers of a very compact form, ſo as to admit of its being packed up in a pretty ſmall box; but when in uſe, it muſt be ſet upon a table, as is repreſented in fig. 14, where, it muſt be remarked, that the balance may be moved a little way up or down, either by means of the ſtring which goes along the ſtand, in the common way, or by ſome other mechanical contrivance which needs not be particularly deſcribed.

We ſhall now proceed to ſtate the practical methods of determining the ſpecific gravities of bodies of various ſpecies; which methods are nothing more than practical applications of the Propoſitions of the preceding chapter, as will appear by obſerving at the end of the Rules, the quotation of the Propoſitions upon which thoſe rules depend.

Problem I. *To aſcertain the ſpecific gravity of a pretty large ſolid, which is heavy enough to ſink in water.*

Rule. Suſpend the ſolid by means of as ſlender a thread as may be juſt ſufficient to hold it, to the hook under the ſcale C, ſo as to hang at the diſtance of ſix or ſeven inches below that ſcale, and by putting weights in the oppoſite ſcale D, find out its exact weight in air, that is out of the water. Then place the jar E, about three-quarters full of rain or diſtilled water, juſt under the ſcale C, which is the caſe actually repreſented in the figure; let the ſolid body be immerſed in the water, and either by removing ſome of the weights from the ſcale D, or by putting weights in the ſcale C, find out its exact weight in water. Subtract the latter weight from the former, and note the remainder. Laſtly, divide the weight of the ſolid out of the water by that remainder, and the quotient will expreſs its ſpecific gravity. (Prop. V.)—See the precautions which follow the example.

Example. A piece of ſilver was found to weigh in air (that is, out of the water) 136 grains, and in water 123,73 grains. The latter weight being ſubtracted from the former, there remained 12,25 grains. Laſtly, 136 was divided by 12,25, and the quotient 11,091 expreſſed the ſpecific gravity of the piece of ſilver.

Before we proceed any farther, it is neceſſary to prevent any poſſible miſtake, by the ſtatement of the following

General precautions. The water in which the ſolid is to be weighed, beſides its being either diſtilled or rain water, muſt be quite clean.—Its temperature, as well as that of the ſolid, muſt be as near as poſſible to 62° of Fahrenheit's thermometer,

meter; for which purpoſe the ball of the thermometer muſt be placed in the water, and the temperature is adjuſted by the addition of hot or cold water. — If the ſolid body be ſoluble in water, or if it be porous enough to abſorb any water, then it muſt be varniſhed, or ſmeared over with ſome oily or greaſy ſubſtance; but in that caſe ſome allowance muſt be made on account of the varniſh, &c. —When the ſolid is weighed in water, its upper part ought to be a little way below the ſurface of the water; for inſtance, about an inch; and it muſt by no means be ſuffered to touch the ſides or bottom of the jar.—Care muſt be had that no bubbles of air adhere to the ſolid under water; for they would partly buoy it up. Theſe may be eaſily removed by means of a feather. — The ſolid muſt be of a compact form, and free from accidental or artificial vacuities, ſo as not to harbour any air; for otherwiſe its ſpecific gravity cannot be aſcertained by weighing in water, &c. Thus a piece of ſilver, which is much heavier than water, may be formed into a hollow ſphere, which will appear to be much lighter than water; for if this ſphere were immerſed in water, it would diſplace a quantity of water which is equal not only to the ſilver, but alſo to the ſpace which is contained in the ſphere*. — Theſe precautions muſt be attended to

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* It is for this reaſon that a ſhip might be made of iron, or of copper, or, in ſhort, of any ſubſtance whoſe ſpecific gravity

to in the practical performance of the preceding as well as of the following problems of this chapter, as far as they may be concerned in them.

Problem II. *To aſcertain the ſpecific gravity of ſolids, or compact bodies, that are ſufficiently heavy to ſink in water, which are not ſoluble in that fluid, but are too ſmall to be tied by means of a thread.*

Rule. Suſpend the glaſs bucket G by the interpoſition of a thread, to the hook of the ſcale C, and find its weight in air; then place the ſubſtance, which is to be tried, in it, and weigh it again. The former weight ſubtracted from the latter leaves the weight of the ſubſtance in air. This being done, the ſame operation muſt be repeated in water; that is, let the loaded bucket be weighed in water, then remove its contents, and weigh the bucket alone in water. Subtract the latter weight from the former, and the quotient is the weight in water, of the ſubſtance under examination. Having thus obtained the weights of that ſubſtance in water and out of water, you will then proceed according to the preceding problem; viz. ſubtract its weight in water from its weight in air, and note the remainder. Divide its weight in air by this remainder, and the quo-

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gravity far exceeds that of water; and yet it would float as well as a ſhip which is made of wood, in the uſual way.

tient will expreſs its ſpecific gravity. (Prop. V.) — Obſerve the general precautions at the end of Problem I. p. 57.

By this means the ſpecific gravity of diamonds and other ſmall precious ſtones, as alſo of grains of platina, of filings of metal, of mercury, &c. may be aſcertained.

Example. The glaſs bucket being ſuſpended from the hook of the ſcale C, was counterpoiſed by weights in the oppoſite ſcale D. Some gold-duſt was then placed in it, and by adding more weights into the ſcale D, its weight (viz. of the gold-duſt alone) was found to be 460,6 grains. The loaded bucket was then weighed in water, and was found to weigh 736,1 grains; and after having removed the gold-duſt from the bucket, the latter by itſelf was found to weigh in water 300 grains; which being ſubtracted from 736,1, left 436,1 grains for the weight of the gold in water. Then this weight of the gold in water (viz. 436,1) was ſubtracted from its weight in air (viz. 460,6) and the remainder was 24,5. Laſtly, the weight of the gold in air, viz. 460,6 was divided by the remainder 24,5, and the quotient 18,8 expreſſed the ſpecific gravity of the gold-duſt.

Problem III. *To aſcertain the ſpecific gravity of a ſolid body lighter than an equal bulk of water*, viz. ſuch as will not ſink in it.

Rule.

Rule. Take another body of a compact form, but much heavier than an equal bulk of water, ſo that when this body is connected with the body in queſtion, they may both ſink in water. This being prepared, aſcertain the weight of the lighter body in air, and the weight of the heavier body in water. Then tie, by means of thread, both bodies together, but not ſo cloſely as to exclude the water from, or to harbour bubbles of air, between them; and weigh them both in water. Now ſince the heavy body is partly buoyed up by the lighter body, the weight of both in water will be leſs than the weight of the heavier body alone. Subtract the former from the latter, and add the remainder to the weight of the lighter body in air; for this ſum is the weight of a quantity of water equal in bulk to the lighter body. Therefore the weight of the lighter body in air muſt be divided by the laſt-mentioned ſum, and the quotient will expreſs the ſpecific gravity of the lighter body. (Prop. V. Cor. 3, and 4) — Obſerve the general precautions at the end of Prob. I. p. 57.

Example. A piece of elm, being varniſhed in order to prevent its abſorbing any water, was found to weigh in air 920 grains. A piece of lead, which was choſen for this purpoſe, was found to weigh in water 911,7 grains. The piece of elm and the piece of lead were tied together, and being ſuſpended from the hook of the ſcale C,

&c. in the uſual manner, were found to weigh in water 331,7 grains, viz. 580 grains leſs than the lead alone; therefore 580 was added to 920 (viz. to the weight of the elm in air) and made up the ſum of 1500. Laſtly, 920 was divided by 1500, and the quotient 0,6133 expreſſed the ſpecific gravity of the piece of elm.

It is almoſt ſuperfluous to obſerve, that the ſpecific gravities of bodies that are lighter than water, are leſs than unity.

Problem IV. *To aſcertain the ſpecific gravities of ſmall bodies (ſuch as ſaline powders, &c.) which are ſoluble in, or abſorb, water, and are not capable of being varniſhed.*

Rule. The ſubſtance in queſtion muſt be reduced into fine powder, unleſs it be already in that ſhape. Take a clean glaſs phial, ſuch as H, fig. 14, put it in one of the ſcales of the balance, and counterpoiſe it by placing weights in the oppoſite ſcale; then fill the phial with the powder in queſtion, ramming it as cloſe as poſſible, and quite up to the top. This done, replace the phial in the ſame ſcale in which it ſtood before, and by adding more weights in the oppoſite ſcale, find out the exact weight of the powder alone. Now remove the powder from the phial, fill the latter with diſtilled or rain water, and placing it in the ſcale as before, aſcertain the weight of the water alone. By this means you have the weights of equal quantities of the powder and of water, which are exactly as their ſpecific gravities; but the ſpecific gravity of water is not in this caſe expreſſed by unity; therefore ſay, as the weight of the water is to the weight of the powder, ſo is unity to a fourth proportional, which is the ſpecific gravity of the powder when that of water is reckoned unity; that is, divide the weight of the powder by the weight of the water, and the quotient will expreſs the ſpecific gravity of the powder.

In certain caſes the ſaline ſubſtances or other ſmall bodies, if the reducing them to powder be objected to, may be weighed in the bucket, according to Problem II. but inſtead of water they muſt be weighed in ſome other fluid, in which they are not ſoluble, and whoſe ſpecific gravity is already known; for the ſpecific gravities thus found may be eaſily referred to that of water.

Example. The phial H full of a certain ſalt was found to weigh 630 grains (meaning the ſalt alone, independent of the phial) and the ſame phial full of rain-water was found to weigh 450 grains, (viz. the water alone); therefore 630 was divided by 450, and the quotient 1,4 expreſſed the ſpecific gravity of the ſalt.

Problem V. *To aſcertain the ſpecific gravities of fluids.*

Rule. This may be done either by the method laſt-mentioned, which indeed is the moſt proper, it being the moſt accurate, for nice experiments; or in the following manner:

Suſpend the glaſs ball F, fig. 14, or a piece of metal, to the hook of the ſcale C, and find ſucceſſively its weight in air, its weight in water, and its weight in any other fluid you wiſh to try. Subtract its weight in water from its weight in air, and the remainder is its loſs of weight when weighed in water. Alſo ſubtract its weight in the other fluid from its weight in air, and the remainder is its loſs of weight in the other fluid. Now thoſe two laſt weights are exactly as the ſpecific gravities of the two fluids reſpectively. But the ſpecific gravity of water is not, in this caſe, expreſſed by unity; therefore ſay, as the loſs of weight in water is to the loſs of weight in the other fluid, ſo is unity to a fourth proportional; that is, divide the loſs of weight in the other fluid by the loſs of weight in water, and the quotient will expreſs the ſpecific gravity of the other fluid.

For this purpoſe a glaſs ball with a bit of platina wire, are preferable to other ſubſtances, becauſe amongſt all the variety of fluids there are fewer that have any action upon glaſs and platina than upon any other ſolid; yet they are corroded by one or two fluids, and therefore when theſe are to be tried, the method of Problem IV. muſt be adopted; but, the phial muſt conſiſt of ſuch a ſubſtance as is not liable to be corroded by the fluid in queſtion; or the glaſs phial may be lined in the inſide with a film of bees-wax, which is eaſily done

done by warming the phial; for this film will prevent its being corroded.*

Example. A glaſs ball which weighed 100 grains in air, was found to weigh 60 grains in water, and 70 grains in another fluid; ſo that the loſs of weight in water was 40 grains, and the loſs of weight in the other fluid was 30 grains; therefore 30 was divided by 40, and the quotient 0,75 expreſſed the ſpecific gravity of the other fluid.

The knowledge of the ſpecific gravities of bodies is of the utmoſt conſequence in philoſophy, and in other ſciences, as alſo in the ſeveral arts which depend on thoſe ſciences. Independent of thoſe bodies which are pretty uniform, and whoſe ſpecific gravities are well known, it frequently happens in chemiſtry, in the practice of ſeveral arts, and in ſome departments of civil ſociety, that the ſpecific gravities of various bodies, eſpecially of compounds, muſt be actually aſcertained on particular ſpecimens. The ſtrength and activity of divers chemical articles is accompanied with a proportionate degree of ſpecific gravity; there-

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* The ſpecific gravity of air, and other elaſtic fluids analogous to air, is aſcertained by firſt filling a phial with water and weighing it, then filling the ſame with the elaſtic fluid in queſtion, and weighing it again, after the manner of Problem IV.; but the phial which is neceſſary for the purpoſe of confining elaſtic fluids, as alſo the mode of filling it, will be deſcribed hereafter.

fore the knowledge of the latter is uſed as an indication of the former. The ſtrength of ſpirits is determined both in diſtilleries, and by the officers of the exciſe, from their ſpecific gravities. The aſſayers and the refiners of ſilver and gold frequently make uſe of the ſame means for determining the quality of their articles, and ſo forth.

This extenſive uſe of the knowledge of ſpecific gravities has produced a variety of contrivances, under the names of *Eſſay inſtrument*, *Hydrometer*, *Areometer*, *Gravimeter*, and *Peſe-liqueur*, for the purpoſe of aſcertaining the ſpecific gravities of different bodies in an expeditious manner.

The conſtruction of all thoſe inſtruments depends upon the principle of the 5th Propoſition of the preceding chapter, viz. that if a body whoſe ſpecific gravity is leſs than that of certain fluids, be cauſed to float ſucceſſively upon thoſe fluids, it will ſink deeper into the lighter than into the heavier fluid. Or that a greater addition of weight is required to keep the ſame part of the floating body below the ſurface of a heavier, than of a lighter, fluid.

The ſimpleſt hydrometer is repreſented in fig. 13. of Plate X. It conſiſts of a graduated rod or ſtem, CA, about 4 inches long, which is fixed to the bulb A. From the loweſt part of A another ſtem proceeds a ſhort way, and terminates in a ſmaller bulb B. The bulb B is partly or entirely filled with ſome metallic ſubſtance, generally quickſilver, which anſwers two purpoſes; it renders the inſtrument juſt heavy enough to ſink as far as ſome part of the ſtem CA below the ſurface of the fluid which is to be tried by it; and it ſerves to keep the inſtrument upright in the fluid; hence it is placed, as ballaſt, in the loweſt part of the inſtrument.

Now when the ſpecific gravity of a fluid is to be determined, the fluid is put into a glaſs jar, or other convenient veſſel, and the hydrometer is ſet to float in it; then the ſpecific gravity of the fluid is indicated by the number of the diviſions of the ſtem AC which remain above the ſurface of the fluid; or (which amounts to the ſame thing) by thoſe which remain below that ſurface; thoſe diviſions being made, by trial and adjuſtment, to repreſent parts of the whole bulk of the inſtrument. Suppoſe, for inſtance, that the bulk of the whole inſtrument be equal to 1000 cubic tenths of an inch, and that each of the diviſions of the ſtem repreſents one of thoſe parts. Then if this inſtrument be placed firſt in one fluid and then in another, and if it be found to ſink as far as the 40th diviſion (counting from the top) in one fluid, and as far as the 30th in the other fluid, it is evident that of the 1000 parts of the bulk, 960 have been ſunk in the former fluid, and 970 in the latter; therefore, ſince the ſpecific gravities of thoſe fluids are inverſely as the parts immerſed, the ſpecific gravity of the former is to that of the latter as 970 is to 960. If water be one of the

fluids,

fluids, for inſtance the former; then ſay, as 970 is to 960, ſo is one to a fourth proportional, which is the ſpecific gravity of the other fluid when that of water is called unity. But the diviſions on moſt of thoſe inſtruments are numbered ſo as to indicate immediately the ſpecific gravity of a fluid in compariſon with that of water, which is reckoned one.

Hydrometers of the above-mentioned ſort have been made of glaſs for ſuch fluids as corrode metals; and of metal, which is more durable, for ſuch fluids as have no action upon it. But its peculiar imperfections are two in number; 1ſt, It can ſerve only for thoſe fluids which differ very little in ſpecific gravity; for if the diviſions of the ſtem repreſent ſmall portions of the bulk of the inſtrument, then the whole length of the ſtem will likewiſe repreſent no great part of the whole bulk; hence very little difference of ſpecific gravity can be indicated by all the diviſions which are upon it; and if the diviſions repreſent conſiderably large portions of the inſtrument, then the inſtrument will not indicate ſmall differences of ſpecific gravity. 2dly. The inequalities of the ſtem, and the ſmall quantity of fluid, which in the common manner of uſing the inſtrument can hardly be prevented from adhering to that part of the ſtem which is juſt above the fluid, render it inaccurate in a greater or leſs degree.

The

The removal of the firſt of thoſe imperfections has been attempted either by adapting different ſtems to the ſame inſtrument; ſo that a heavier or a lighter ſtem might be put on, according to the nature of the fluid under examination; or by affixing certain weights to the inſtrument, and altering the value of the diviſions accordingly.

The ſecond imperfection has been removed by removing the diviſions from the ſtem, and indeed by this means the firſt imperfection is in great meaſure removed; viz. the ſtem contains one mark about its middle, and the inſtrument is cauſed to ſink always to that mark in different fluids, by the addition of different weights. Then the ſpecific gravities are indicated by thoſe weights.

The weights in ſome hydrometers are ſcrewed to, or ſimply laid in a cup fit to receive them at the bottom of the inſtrument. In others the weights are placed in a cup which is fixed on the top of the ſtem, and which of courſe remains out of the fluid. But as the laſt method is apt to render the inſtrument top-heavy; therefore ſome of them have been conſtructed with two cups, viz. one at top and another at their lower part; and proper weights are to be placed in both, viz. the coarſeſt or largeſt in the lower, and the minuteſt in the upper cup.

Such inſtruments have alſo been uſed for determining the ſpecific gravities of ſmall ſolids. In this

this caſe the ſolid is placed in the lower cup, and ſuitable weights are put into the upper cup.

Another inſtrument has alſo been uſed for expeditiouſly determining the ſpecific gravities of fluids. It conſiſts of a ſeries of glaſs bubbles, increaſing and decreaſing in ſpecific gravity from the ſtandard fluid, in a known ratio. When a fluid is to be tried, thoſe balls, which are all numbered, muſt be placed ſucceſſively in the fluid, and it will be found that ſome of them will ſink to the bottom of the veſſel, whilſt others will remain on the ſurface of the fluid; but that bubble which is preciſely of the ſame ſpecific gravity with the fluid, will remain in any part of it, without ſhewing any tendency either to aſcend or to deſcend.

All thoſe inſtruments muſt be reckoned inferior to the hydroſtatical balance and apparatus, and that on various accounts, which will eaſily occur to any reflecting mind. Expedition of operation, and portability, are the only circumſtances which have recommended them. But the uſe of the balance is by no means long and intricate; and it is unqueſtionably the leaſt equivocal. With reſpect to portability, it muſt be obſerved that no ſingle hydrometer, even of the beſt ſort known, can be uſed for aſcertaining the ſpecific gravities of all ſorts of bodies; and if many of them muſt be had in readineſs, then the bulk of them all will more than equal that of a tolerably uſeful balance and apparatus. Therefore we may conclude with affirming, that

that the hydroſtatical balance and apparatus is upon the whole the moſt accurate, the moſt durable, and the moſt portable apparatus for the purpoſe of aſcertaining ſpecific gravities in general; and that the uſe of hydrometers may be recommended to ſuch perſons only as are obliged to try a great variety of fluids which do not vary much in gravity; viz. to diſtillers, to officers of the exciſe, &c.

Thus far I have endeavoured to give a ſhort but comprehenſive account of the inſtruments, which, beſides the balance, have been contrived for the purpoſe of aſcertaining ſpecific gravities. A particular deſcription of them all is incompatible with the nature and limits of this work. But if the reader be deſirous of examining the particular conſtructions and uſes of ſuch inſtruments, he may conſult the books which are mentioned in the note*.

In determining ſpecific gravities of bodies, different experimenters have uſed water of various, and ſometimes of unknown temperatures; generally how-

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* Boyle's Works, quarto edition of 1772, vol. IV. p. 204.—Phil. Tranſactions, vol. 36, vol. for 1793, p. 164.—Memoirs of the Mancheſter Society, vol. 1.—Ramſden's Account of Experiments to determine the Spec. Grav. of Fluids; London, 1792.—Annales de Chimie, vol. 21.—Baumé's Elem. de Pharmacie.—Nicholſon's Journal of Nat. Phil. No. I. III.—De Prony's Architecture Hydraulique, from § 614 to § 626.

ever, between the 50th and 65th degree of Fahrenheit's thermometer. But the beſt tables of ſpecific gravities have been formed at the temperature either of about 55° or 60°.

A conſiderable difference does frequently appear in thoſe tables between the ſtatements of the ſpecific gravities of the ſame bodies. This difference ſometimes affects even the firſt decimal figure; in one table, for inſtance, we find that a certain body is 2,135, and in another table that it is 2,245. It is evident that this difference cannot be attributed to the different ſpecific gravities of water at thoſe temperatures; for that difference will not affect even the third decimal figure; but it muſt be attributed to other cauſes, the principal of which are the imperfection of the inſtruments with which the bodies are weighed, and the various qualities of the bodies themſelves, which are occaſioned by innumerable and often apparently trifling circumſtances. Hence it follows that in forming a table of ſpecific gravities the greateſt care ſhould be had to attain the utmoſt degree of accuracy; but in the uſe of ſuch a table, ſome latitude muſt be allowed to the poſſible error in the ſtatement of the ſpecific gravities, in proportion as the conſtitutions of the bodies are more or leſs variable.

The following table has been formed by comparing the beſt tables of ſpecific gravities now extant; by conſulting the works of the beſt authors who have treated of particular ſubſtances; and by

repeating

repeating ſeveral of their experiments. But after all, it muſt be acknowledged, that the difficulty of reconciling the different diſcordant ſtatements, and of obtaining genuine ſpecimens for actual experiments, is ſo very great, that the utmoſt diligence will not be ſufficient to obtain certainty and preciſion*. The reader will find the ſubſtances arranged in the following manner. The metallic ſubſtances occupy the firſt place; theſe are followed by the earths and ſtones; then come the inflammable, the vegetable, the animal, and laſtly the fluid ſubſtances.—When a ſubſtance is ſtated with two ſpecific gravities, the meaning is that the ſpecific gravity of that ſubſtance is various, viz. ſome

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* If the reader be deſirous of examining this ſubject in a more particular manner, he may conſult Dr. Davis's excellent Paper on Specific Gravities, in the Phil. Tranſ. vol. XLV. p. 416; or in the Abridg. vol. X. p. 206. This paper contains all that which had been done previous to the year 1747, relative to the ſubject.—M. Briſſon's Tables of Specific Gravities.—M. de Prony's Archit. Hydr.—Mr. Gilpin's excellent Tables of the weights, &c. of mixtures of ſpirit and water in different proportions in the Phil. Tranſ. for the year 1794, page 275.—Kirwan's Mineralogy, ſecond edit.—I do not refer the reader to a vaſt number of other tables, which are either leſs correct, or copied from the abovementioned works. With reſpect to the gravity of air under different degrees of preſſure, as alſo of heat, &c. he may peruſe a moſt valuable paper of Col. Roy, in the Phil. Tranſ. vol. LXVII.

ſpecimens of it are heavier than others, but between the annexed limits. When that variation is not very great, then the mean ſpecific gravity alone is expreſſed. In ſelecting the articles for the following table, I have rejected moſt of thoſe which occur leſs frequently, or whoſe ſpecific gravity is too fluctuating; and for a ſimilar reaſon the expreſſions of the ſpecific gravities have been extended to a greater number of decimals with certain ſubſtances than with others.

TABLE of the Specific Gravities of different Subſtances at the Temperature of 60° Fahr. Therm.; unleſs ſome other Temperature be expreſsly mentioned.

		Spec. Grav.
Platina	in grains, as it comes from the mine - - - - - -	15,600 17,200
	in grains, purified by boiling in nitrous acid - - - -	17,500 18,500
	purified and forged - - - -	20,336
	the ſame formed into a plate by being compreſſed through the rollers of a flatting-mill - -	22,069

Gold

		Spec. Grav.
Gold	pure, or of 24 carats fine,* fuſed, but not hammered	19,258
	the ſame hammered	19,362
	of the Engliſh ſtandard, being 22 carats fine, fuſed, but not hammered	18,888
	of the Engliſh guinea	17,629
	of the ſtandard of the French coin in the year 1780, being 21 $\frac{22}{32}$ carats fine; fuſed only	17,402
	the ſame coined	17,647
	of the French ſtandard for trinkets in the year 1780 being 20 carats fine, ſimply fuſed	15,709
	the ſame hammered	15,774
	of the Spaniſh coin in the year 1780	17,655
	of the Portugal coin in the year 1780	17,966

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* The fineneſs of gold, or the proportion of alloy (that is, of other metal) it contains, is reckoned by imaginary weights, called *carats*. The whole maſs is conceived to be divided into 24 equal parts, viz. 24 carats, and the purity of the ſpecimen is expreſſed by the number of carats of pure gold it contains. Thus gold of 18 carats fine, means a compound of $\frac{18}{24}$ths of pure gold, and $\frac{6}{24}$ths of ſome other metal; — gold of 22 carats fine, contains $\frac{22}{24}$ths of pure gold and $\frac{2}{24}$ths of alloy; and pure gold is called gold of 24 carats fine.

		Spec. Grav.
Mercury, or Quickſilver[*]	at 32° of heat	13,619
	at 60° of heat	13,580
	at 212° of heat	13,375
Silver	fine, ſimply fuſed	10,474
	the ſame hammered	10,511
	ſterling, or ſtandard, containing 11 oz. 2 dwt. of fine ſilver in the pound troy; ſimply fuſed	10,200
	of the ſtandard of the French coin in the year 1780, ſimply fuſed	10,047
	the ſame coined	10,408
Copper	ſimply fuſed[†]	7,788
	the ſame hammered	8,878
Braſs, being a compound metal, varies between		7,600 8,800

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[*] The ſpecific gravity of mercury varies a little with various ſpecimens; but the proportion at different degrees of heat is nearly the ſame; the bulk of mercury increaſing by the quantity 0,000102 for every degree of heat; its bulk at 32° being called one or unity.

[†] Such is the uſual ſpecific gravity of copper, reckoned pure; but it is frequently found of ſuperior gravity. Bergman found the ſpecific gravity of Swediſh copper to be 9.3243; but this may poſſibly be a miſtake; for he likewiſe ſets the ſpecific gravity of iron at 8,3678, which is conſiderably higher than the beſt ſtatements.

Iron

			Spec. Grav.
Iron	fuſed, but not hammered		7,200 7,600
	forged, in the form of bars		7,788
	in the ſtate of	ſteel ſoft	7,833
		ſteel hammered	7,840
		ſteel hardened in water[*]	7,816
		ſteel hammered, and then hardened in water	7,818
Tin	the pureſt from Cornwall, ſimply fuſed[†]		7,170 7,291
	the ſame hammered		7,299
	of Malacca, ſimply fuſed		7,296
	the ſame hammered		7,306
Lead, whether hammered or not			11,445 11,352
Zinc, ſimply fuſed			7,190

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[*] The expanſion of ſteel in hardening, beſides its being indicated by the decreaſe of ſpecific gravity, is alſo deciſively ſhewn by the following experiment of Mr. Robert Pennington. — A piece of ſteel which when ſoft meaſured in length 2,769 inches, after being hardened by plunging it red-hot in cold water, was found to meaſure 2,7785; and after having been let down to a blue temper, it meaſured 2,768 inches.

[†] Gellert aſſerts that the ſpecific gravity of the tin of Gallicia in Spain is 7,063.

Antimony,

		Spec. Grav.
Antimony, in a metallic ſtate, ſimply fuſed		6,624 6,860
Biſmuth, in a metallic ſtate, ſimply fuſed		9,756 9,822
Cobalt, in a metallic ſtate, ſimply fuſed		7,645 7,811
Smalt, or blue glaſs of cobalt		2,440
Nickel, of the pureſt ſort		7,000 9,000
Sulphurated nickel, or the mineral called *kupfer nickel* by the Germans		6,620
Manganeſe, in a metallic ſtate		6,990
Arſenic, fuſed[*]		8,310
Uranite in a metallic ſtate		6,440
Jungſten	of a grey colour	5,800 6,028
	of a brown colour	5,570
	in a metallic ſtate [†]	17,600
Molybdena in a metallic ſtate, when ſaturated with water		7,500
Sylvanite, or Tellurite, in a metallic ſtate, twice fuſed		6,343
Titanite		4,180

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[*] This ſp. gr. has been ſtated on the authority of Muſchenbroek and Bergman; but Briſſon ſtates it at 5,7633.

[†] This ſpecific gravity reſts upon the authority of Elhuyart. It may poſſibly be a miſtake. See Kirwan's Mineralogy, ſecond edit. vol. 2, p. 308.

		Spec. Grav.
Manachanite		4,427
Rock cryſtal	colourleſs	2,650
	roſe coloured	2,670
Quartz		2,640 2,670
Amethyſt		2,655
Emerald		2,775
Berryll, or Aigue Marine		2,650 2,722
Praſium		2,580
Ruby	oriental	4,283
	Brazilian	3,531
Topaz	oriental	4,011
	Brazilian	3,536
	from Saxony	3,564
Sapphire	oriental	3,991
	Brazilian	3,130
Hyacinth		3,687
Jargon or Zircon		4,416
Garnet	oriental, carbuncle	4,000 4,188
	common	3,800
	volcanic	2,468
Chryſolite		3,340 4,410
Icelandic agate		2,348
Rubellite or red ſhorl of Siberia		3,100

Shorl

	Spec. Grav.
Shorl	2,920 3,212
Shorlite	3,530
Tourmalin	3,050 3,155
Ædelite, or Siliceous Zeolite	2,515
Lapis lazuli	2,760 2,945
Chryſopraſium	2,489
Opal	1,700 2,118
Hyalite or Lava Glaſs	2,110
Calcedony	2,600 2,665
Cornelian	2,597 2,630
Cat's Eye	2,560 2,660
Flint	2,580 2,630
Hornſtone	2,530 2,653
Jaſper	2,500 2,820
Ægyptian pebble	2,564
Sinople	2,691
Heliotropium	2,620 2,700

Woodſtone

	Spec. Grav.
Woodſtone	2,045 2,675
Felſpar	2,437 2,600
Labradore ſtone	2,670 2,692
Agates	2,580 2,666
Strontian earth	3,400 3,644
Corundum ſtone, or adamantine ſpar	3,876 4,166
Granites	2,538 2,956
Chalk	2,315 2,657
Arenaceous limeſtone	2,742
Compact limeſtone	1,386 2,720
Foliated limeſtone	2,710 2,837
Common ſpar	2,693 2,778
Marbles	2,700
Gypſum	2,167 2,311
Aerated barytes	4,300 4,338

		Spec. Grav.
Baroſelenite		4,400 4,865
Lapis hepaticus		2,666
Talk, common, or Venetian		2,700 2,800
Indurated ſteatites	before it has abſorbed any water	2,583
	after having imbibed water	2,632
Baſalt from the Giant's Cauſeway		2,864
Pumice-ſtone		0,914
Oriental pearls		2,683
Diamond	oriental colourleſs	3,521
	oriental roſe-coloured	3,531
	oriental orange-coloured	3,550
	oriental green-coloured	3,523
	oriental blue-coloured	3,525
	Brazilian	3,444
Aſphaltum	coheſive	1,450 2,060
	compact	1,070 1,165
Mineral tallow		0,770
Native mineral carbon, or pit-coal		1,400 1,550
Plumbago		1,987 2,089
Sulphur	native	2,033
	fuſed	1,990

Amber

		Spec. Grav.
Amber		1,078 1,080
Glaſs	white flint	about 3,300
	crown	about 2,520
	common plate	about 2,760
	yellow plate	2,520
	white, or cryſtal, of France	2,892
	St. Gobin's	2,488
Porcelain	China	2,384
	Seves	2,145
	from Saxony	2,493
Copal	tranſparent	1,045
	of Madagaſcar and China	1,061
Ambergris		0,780 0,926
Common roſin		1,072
Sandarac		1,092
Maſtic		1,074
Storax		1,109
Elemi		1,018
Labdanum		1,186
Reſin or gum of guaiac		1,228
Reſin of jalap		1,218
Dragon's blood		1,204
Gum lac		1,139
Elaſtic gum, or *Caoutchouc*, commonly called India rubber		0,933
Camphor		0,988
Gum ammoniac		1,207
Myrrh		1,360

	Spec. Grav.
Gamboge	1,221
Scammony about	1,235
Aſſafœtida	1,327
Sarcocolla	1,268
Gum arabic	1,452
Gum tragacanth	1,316
Inſpiſſated juice of liquorice	1,722
Opium	1,336
Indigo	0,769
Arnotto	0,595
Yellow, or bees, wax	0,965
White wax	0,968
Dry ivory	1,825
Spermaceti	0,943
Honey	1,450
Fat of beef, veal, mutton, &c.	0,923 0,948
Heart of oak, 60 years old	1,170
Cork	0,240
Trunk of elm	0,671
Trunk of aſh	0,845
Beech wood	0,852
Alder wood	0,800
Maple wood	0,755
Walnut wood	0,671
Willow	0,585
Fir wood	0,498 0,550
Poplar wood	0,383
White Spaniſh poplar wood	0,529

	Spec. Grav.
Apple tree	0,661
Quince tree	0,793
Medlar tree	0,944
Plumb tree	0,705
Olive tree	0,927
Cherry tree	0,715
Filbert tree	0,600
French box wood	0,912
Dutch box wood	1,328
Dutch yew tree	0,788
Spaniſh yew tree	0,807
Spaniſh cypreſs wood	0,644
American cedar tree	0,560
Pomegranate tree	1,354
Spaniſh mulberry tree	0,897
Lignum vitæ	1,333
Orange tree	0,705
Red Brazil wood	1,031
Logwood	0,913
Saſſafras	0,482
Peruvian bark	0,784

Diſtilled Water, or Rain Water, at the following Degrees of Temperature, Fahren. Therm.

Heat.	Spec. Grav.
30	1,00074
31	1,00078
32	1,00082
33	1,00085
34	1,00088
35	1,00090
36	1,00092
37	1,00093
38	1,00094
39	1,00094
40	1,00094
41	1,00093
42	1,00092
43	1,00090
44	1,00088
45	1,00086
46	1,00083
47	1,00080
48	1,00076
49	1,00072
50	1,00068
51	1,00063
52	1,00057
53	1,00051
54	1,00045
55	1,00038
56	1,00031
57	1,00024
58	1,00016
59	1,00008
60	1,00000
61	0,99991
62	0,99981
63	0,99971
64	0,99961
65	0,99950
66	0,99939
67	0,99928
68	0,99917
69	0,99906
70	0,99894
71	0,99882
72	0,99869
73	0,99856
74	0,99843
75	0,99830
76	0,99816
77	0,99802
78	0,99788
79	0,99774
80	0,99759
85	0,99681
90	0,99598
95	0,99502
100	0,99402 *

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* Phil. Tranſ. vol. for 1792; Table II. p. 428; and vol. for 1794, p. 382.

	Spec. Grav.
Sea water*	1,026
Water of the Dead Sea	1,240
Naphtha	0,847
Petrol	0,878
Sulphuric, or vitriolic, acid	1,841
Nitric acid	1,272
Muriatic acid	1,194
Red acetous acid	1,025
White acetous acid	1,014
Diſtilled acetous acid	1,010
Acetic acid	1,063
Solution of cauſtic ammoniac, or fluid volatile alkali	0,897
Spirit, or volatile oil, of turpentine	0,870
Liquid turpentine	0,991
Volatile oil of lavender	0,894
Volatile oil of cloves	1,036
Volatile oil of cinnamon	1,044
Oil of olives	0,915
Oil of ſweet almonds	0,917
Lintſeed oil	0,940
Oil of poppy-ſeed	0,929
Whale oil	0,923
Woman's milk	1,020
Mare's milk	1,035
Aſs's milk	1,036

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* Is ſaid to be heavier in the torrid zone, and far from the land.

	Spec. Grav.
Goat's milk	1,034
Ewe's milk	1,04
Cow's milk	1,033
Cow's whey	1,019
Human urine	1,015 1,026
Human blood	1,054
Craſſamentum of human blood	1,126
Alcohol, or pure ſpirituous liquor*	0,798

Spirit

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* The rectification of ſpirits (whether from wine, or rum, or malt-liquor, for it ſeems to be all the ſame thing) has been carried to a very great degree of perfection, by means of repeated ſlow diſtillations, together with the addition of alkaline ſalts, which have a very great power of abſorbing the aqueous part of the liquor. The lighteſt ſpirit, which I find recorded, was uſed in France, by Chauſſier, the ſpecific gravity of which is ſtated at 0,798. See l'Encyclopédie Méthodique, art. *Alcohol.* In England it has been obtained, not without extraordinary care and attention, of the ſpecific gravity 0,813. Phil. Tranſ. vol. for 1790, p. 324. But with moderate attention it may be conſtantly obtained of the ſp. gr. 0,82514, and of this quality was the ſpirit which was uſed by Mr. Gilpin in his experiments for the conſtruction of his very accurate Tables, wherein, for conveniency's ſake, the trifling fraction 0,00014 was omitted (ſee the Phil. Tranſ. for the year 1790, article XVIII; for the year 1792, art. XXII; and for the year 1794, art. XX.); from which the above ſpecific gravities of water, of ſpirit, and of the mixtures of water and ſpirit, have been extracted.

The

	Spec. Grav.
Spirit uſed for the Tables which are inſerted in the Phil. Tranſ. for 1794	0,825
Proof-ſpirit, according to the Engliſh Exciſe Laws*	0,916

Specific Gravities, at different Temperatures, of Spirit, whoſe Specific Gravity at 60° is 0,825.

Heat.	Spec. Grav.
30°	0,83896
35°	0,83672
40°	0,83445
45°	0,83214
50°	0,82977
55°	0,82736

The laſt-mentioned gentleman having procured a ſpecimen of ſpirit of ſuperior levity, its ſpecific gravity being 0,814196 at 60° of temperature, endeavoured to aſcertain what addition of water it might require in order to equal his ſtandard ſpirit; and upon trial found that when 1000 grains of it were mixed with 45 grains of water, the ſpecific gravity of the compound was 0,825153, which may be conſidered as exactly equal to that of his ſtandard ſpirit. Phil. Tranſ. for 1790, p. 340.

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* From the beſt interpretation of the exiſting Acts of Parliament, it ſeems that the ſpecific gravity of what is called *proof-ſpirit*, is 0,916; and that it conſiſts of 100 parts of rectified ſpirit of the ſpecific gravity 0,825, and 62 parts of water by meaſure, or 75 by weight; the whole at 60° of heat, (Dr. Blagden's Report, Phil. Tranſ. for 1790, p. 339.)

Heat.	Spec. Grav.
60°	0,82500
65°	0,82262
70°	0,82023
75°	0,81780
80°	0,81530
85°	0,81283
90°	0,81039
95°	0,80788
100°	0,80543

Real Specific Gravities of Mixtures of Spirit (of the above-mentioned Quality) and Diſtilled Water, at different Temperatures.*

Heat.	100 grains of ſpirit to 5 grains of water.	100 grains of ſpirit to 10 grains of water.	100 grains of ſpirit to 15 grains of water.	100 grains of ſpirit to 20 grains of water.
30°.	0,84995	0,85957	0,86825	0,87585
35	0,84769	0,85729	0,86587	0,87357
40	0,84539	0,85507	0,86361	0,87134
45	0,84310	0,85277	0,86131	0,86907
50	0,84076	0,85042	0,85902	0,86676
55	0,83834	0,84802	0,85664	0,86441
60	0,83599	0,84568	0,85430	0,86208
65	0,83362	0,84334	0,85193	0,85976
70	0,83124	0,84092	0,84951	0,85736
75	0,82878	0,83851	0,84710	0,85493
80	0,82631	0,83603	0,84467	0,85248
85	0,82386	0,83355	0,84221	0,85006
90	0,82142	0,83111	0,83977	0,84762
95	0,81888	0,82860	0,83724	0,84511
100	0,81643	0,82618	0,83478	0,84262

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[*] By *real ſpecific gravities*, are meant the ſpecific gravities found by actual trial, and not thoſe which might have been computed from the quantities of the ingredients. The latter do not agree with the former, on account of the incorporation or loſs of bulk which takes place. See page 51.

Heat.	100 grains of ſpirit to 25 grains of water.	100 grains of ſpirit to 30 grains of water.	100 grains of ſpirit to 35 grains of water.	100 grains of ſpirit to 40 grains of water.
30°.	0,88282	0,88921	0,89511	0,90054
35	0,88059	0,88701	0.89294	0,89839
40	0,87838	0,88481	0,89073	0,89617
45	0,87613	0,88255	0.88849	0,89396
50	0,87384	0,88030	0,88626	0,89174
55	0,87150	0,87796	0,88393	0,88945
60	0,86918	0,87568	0,88169	0,88720
65	0,86686	0,87337	0,87938	0,88490
70	0,86451	0,87105	0,87705	0,88254
75	0,86212	0,86864	0,87466	0,88018
80	0,85966	0,86623	0,87228	0,87776
85	0,85723	0,86380	0,86984	0,87541
90	0,85483	0,86139	0,86743	0,87302
95	0,85232	0,85896	0,86499	0,87060
100	0,84984	0,85646	0,86254	0,86813

Heat.	100 grains of ſpirit to 45 grains of water.	100 grains of ſpirit to 50 grains of water.	100 grains of ſpirit to 55 grains of water.	100 grains of ſpirit to 60 grains of water.
30°.	0,90558	0,91023	0,91449	0,91847
35	0,90345	0,90811	0,91241	0,91640
40	0,90127	0,90596	0,91026	0,91428
45	0,89909	0,90380	0,90812	0,91211
50	0,89684	0,90160	0,90596	0,90997
55	0,89458	0,89933	0,90367	0,90768
60	0,89232	0,89707	0,90144	0,90549
65	0,89006	0,89479	0,89920	0,90328
70	0,88773	0,89252	0,89695	0,90104
75	0,88538	0,89018	0,89464	0,89872
80	0,88301	0,88781	0,89225	0,89639
85	0,88067	0,88551	0,88998	0,89409
90	0,87827	0,88312	0,88758	0,89173
95	0,87586	0,88069	0,88521	0,88937
100	0,87340	0,87824	0,88271	0,88691

Heat.	100 grains of ſpirit to 65 grains of water.	100 grains of ſpirit to 70 grains of water.	100 grains of ſpirit to 75 grains of water.	100 grains of ſpirit to 80 grains of water.
30°	0.92217	0,92563	0,92889	0,93191
35	0,92009	0,92355	0,92680	0,92986
40	0,91799	0,92151	0,92476	0,92783
45	0.91584	0,91937	0.92264	0,92570
50	0,91370	0.91723	0,92050	0,92358
55	0.91144	0,91502	0,91837	0,92145
60	0,90927	0,91287	0,91622	0,91933
65	0.90707	0,91066	0,91400	0,91715
70	0,90484	0,90847	0.91181	0,91493
75	0,90252	0,90617	0,90952	0,91270
80	0,90021	0,90385	0,90723	0,91042
85	0,89793	0,90157	0,90496	0,90818
90	0,89558	0,89925	0,90270	0,90590
95	0,89322	0,89688	0,90037	0,90358
100	0,89082	0,89453	0,89798	0,90123

Heat.	100 grains of ſpirit to 85 grains of water.	100 grains of ſpirit to 90 grains of water.	100 grains of ſpirit to 95 grains of water.	100 grains of ſpirit to 100 grains of water.
30°	0.93474	0.93741	0,93991	0,94222
35	0,93274	0,93541	0,93790	0,94025
40	0,93072	0,93341	0,93592	0,93827
45	0,92859	0,93131	0,93382	0,93621
50	0,92647	0,92919	0,93177	0,93419
55	0,92436	0,92707	0,92963	0,93208
60	0,92225	0,92499	0,92758	0,93002
65	0,92010	0,92283	0,92546	0,92794
70	0,91793	0,92069	0,92333	0,92580
75	0,91569	0,91849	0,92111	0,92364
80	0,91340	0,91622	0,91891	0,92142
85	0,91119	0,91403	0,91670	0,91923
90	0,90891	0,91177	0,91446	0,91705
95	0,90662	0,90949	0,91221	0,91481
100	0,90428	0,90718	0,90992	0,91252

Heat.

Heat.	95 grains of ſpirit to 100 grains of water.	90 grains of ſpirit to 100 grains of water.	85 grains of ſpirit to 100 grains of water.	80 grains of ſpirit to 100 grains of water.
30°	0,94447	0,94675	0,94920	0,95173
35	0,94249	0,94484	0,94734	0,94988
40	0,94058	0,94295	0,94547	0,94802
45	0,93860	0,94096	0,94348	0,94605
50	0,93658	0,93897	0,94149	0,94414
55	0,93452	0,93696	0,93948	0,94213
60	0.93247	0,93493	0,93749	0,94018
65	0,93040	0,93285	0,93546	0,93822
70	0,92828	0,93076	0 93337	0,93616
75	0,92613	0,92865	0,93132	0,93413
80	0,92393	0,92646	0.92917	0.93201
85	0.92179	0,92432	0,92700	0,92989
90	0,91962	0,92220	0,92491	0,92779
95	0,91740	0,91998	0.92272	0,92562
100	0,91513	0,91769	0,92047	0,92346

Heat.	75 grains of ſpirit to 100 grains of water.	70 grains of ſpirit to 100 grains of water.	65 grains of ſpirit to 100 grains of water.	60 grains of ſpirit to 100 grains of water.
30°	0.95429	0,95681	0,95944	0,96209
35	0,95246	0,95502	0,95772	0,96048
40	0,95060	0,95328	0 95602	0,95879
45	0,94871	0,95143	0,95423	0,95705
50	0,94683	0.94958	0.95243	0.95534
55	0,94486	0,94767	0,95057	0,95357
60	0,94296	0.94579	0,94876	0,95181
65	0,94099	0,94388	0,94689	0,95000
70	0,93898	0.94193	0,94500	0,94813
75	0,93695	0,93989	0,94301	0,94623
80	0,93488	0,93785	0,94102	0,94431
85	0 93282	0,93582	0,93902	0.94236
90	0,93075	0,93381	0,93703	0,94042
95	0,92858	0,93170	0.93497	0,93839
100	0,92646	0,92957	0,93293	0,93638

Heat.	55 grains of ſpirit to 100 grains of water.	50 grains of ſpirit to 100 grains of water.	45 grains of ſpirit to 100 grains of water.	40 grains of ſpirit to 100 grains of water.
30°	0,96470	0,96719	0,96967	0,97200
35	0,96315	0,96579	0,96840	0,97086
40	0,96159	0,96434	0,96706	0,96967
45	0,95993	0,96280	0,96563	0,96840
50	0,95831	0,96126	0,96420	0,96708
55	0,95662	0,95966	0,96272	0,96575
60	0,95493	0,95804	0,96122	0,96437
65	0,95318	0,95635	0,95962	0,96288
70	0,95139	0,95469	0,95802	0,96143
75	0,94957	0,95292	0,95638	0,95987
80	0,94768	0,95111	0,95467	0,95826
85	0,94579	0,94932	0,95297	0,95667
90	0,94389	0,94748	0,95123	0,95502
95	0,94196	0,94563	0,94944	0,95328
100	0,93999	0,94368	0,94759	0,95152

Heat.	35 grains of ſpirit to 100 grains of water.	30 grains of ſpirit to 100 grains of water.	25 grains of ſpirit to 100 grains of water.	20 grains of ſpirit to 100 grains of water.
30°	0,97418	0,97635	0,97860	0,98108
35	0,97319	0,97556	0,97801	0,98076
40	0,97220	0,97472	0,97737	0,98033
45	0,97110	0,97384	0,97666	0,97980
50	0,96995	0,97284	0,97589	0,97920
55	0,96877	0,97181	0,97500	0,97847
60	0,96752	0,97074	0,97409	0,97771
65	0,96620	0,96959	0,97309	0,97688
70	0,96484	0,96836	0,97203	0,97596
75	0,96344	0,96708	0,97086	0,97495
80	0,96192	0,96568	0,96963	0,97385
85	0,96046	0,96437	0,96843	0,97271
90	0,95889	0,96293	0,96711	0,97153
95	0,95727	0,96139	0,96568	0,97025
100	0,95556	0,95983	0,96424	0,96895

Heat.	15 grains of ſpirit to 100 grains of water.	10 grains of ſpirit to 100 grains of water.	5 grains of ſpirit to 100 grains of water.
30°	0,98412	0.98804	0,99334
35	0,98397	0,98804	0 99344
40	0,98373	0,98795	0,99345
45	0,98338	0,98774	0,99338
50	0,98293	0,98745	0.99316
55	0,98239	0,98702	0,99284
60	0,98176	0,98654	0,99244
65	0,98106	0,98594	0,99194
70	0,98028	0,98527	0,99134
75	0,97943	0,98454	0,99066
80	0.97845	0,98367	0,98991
85	0,97744	0,98281	0,98912
90	0,97637	0,98185	0,98824
95	0,97523	0,98082	0,98729
100	0,97401	0,97969	0,98625

Sulphuric, or vitriolic, ether	0,7396
Nitric ether	0,9088
Muriatic ether	0,7296
Acetic ether	0,8664

Common, or atmoſpherical, air,* the mercury in the barometer being 29,75 in. high,	at 0° of heat	0,001393
	at 32° of heat	0,001299
	at 60° of heat	0,001220
	at 212° of heat	0,000938

Azotic

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* The ſpecific gravity of common air is not conſtantly the ſame. It increaſes when the mercury riſes in the barometer, and *vice verſa.* Air is alſo expanded by heat, and is

Azotic gas* -	barometer at 29,75 $^{\text{in}}$.	0,001146
Oxygen gas* -	barometer at 29,75 $^{\text{in}}$.	0,001305
Hydrogen gas* -	barometer at 29,75 $^{\text{in}}$.	0,000091
Carbonic acid gas*	barometer at 29,75 $^{\text{in}}$.	0,001682
Nitrous gas* -	barometer at 29,75 $^{\text{in}}$.	0,001411
Ammoniacal gas*	barometer at 29,75 $^{\text{in}}$.	0,000706

Beſides ſhewing the comparative gravities of bodies, which are to be ſeen by bare inſpection, the great uſe of a table of ſpecific gravities is for aſcertaining the real weights of bodies, and that without actually weighing them, when their dimenſions are known, according to what has been already explained in page 43. But for this purpoſe it is neceſſary to know the real weight of a determi-

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is contracted by cold, though not regularly; the greateſt expanſion taking place between the degrees 52° and 72° of Fahrenheit's thermometer, and the leaſt at about 212°. But the expanſion for the ſame degrees of heat alſo varies according to the quantity of moiſture in the air, and to the altitude of the mercury in the barometer. When this altitude is 29,75 and the air is in a mean ſtate of moiſture, it then receives an addition of 0,484 to its bulk by the heat of 212°; viz. a given meaſure of air at 0° becomes 1,484 meaſure at 212°, in which caſe the mean rate of expanſion for each degree is $\left(\frac{0,484}{212}=\right)$ 0,002283.

* Thoſe gaſſes, or artificial airs, are, beſides the influence of preſſure and heat, more fluctuating in their ſpecific gravities. The above ſtatements muſt be underſtood of their pureſt ſtates.

nate bulk of one of the ſubſtances that are mentioned in the table. Now ſince water has been aſſumed as the ſtandard of compariſon for the ſpecific gravities of all other bodies, it will be more convenient to know the real weight of a certain quantity of water, viz. a cubic inch, or a cubic foot of it, than of any other body.

Though at firſt ſight it may appear eaſy to determine the real weight of a certain bulk of water, yet the reader may reſt aſſured, that this determination is attended with very great difficulties, which ariſe from the imperfections of the balance, of the weights, of the meaſures which are employed for meaſuring the bulk, &c.— From the moſt accurate experiments, performed with the beſt inſtruments, and with all the precautions which the preſent ſtate of philoſophical knowledge can ſuggeſt, it has been aſcertained that a cubic inch of diſtilled water at the temperature of 60° weighs 252,576 grains troy; 5760 of which grains are equal to one pound troy.*

The

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* This weight has been calculated for the temperature of 60°, from the ſtatement of Sir George Shuckburg Evelyn's elaborate paper in the Phil. Trans. for the year 1798; where, after the recital of his numerous experiments, this author expreſſes himſelf thus — " In concluſion it appears " then that the difference of the lengths of two pendulums, " ſuch as Mr. Whitehurſt uſed, vibrating 42 and 84 times " in a minute of mean time, in the latitude of London, at

The general rule for determining the real weight of any ſubſtance which is mentioned in the preceding table, when its bulk is known, and is expreſſed in cubical inches, or by any other dimenſion which may be reduced into inches, is as follows. Multiply the weight of a cubic inch of water by the number of cubic inches which expreſſes the bulk of the body in queſtion, and multiply the product by the ſpecific gravity of the body in queſtion. The laſt product expreſſes the real weight of the body.

Thus if it be propoſed to determine the weight of 10 cubic inches of carbonic acid gas, which is the laſt ſubſtance but two in the table, and whoſe ſpecific gravity is 0,001682; multiply the weight of a cubic inch of water by ten, and the product will be 2525,76; then multiply this product by 0,001682, and the product 4,2483283, will expreſs the weight in grains of ten cubic inches of carbonic acid gas, viz. 4¼ grains nearly, at the temperature of 60°, and when the barometer ſtands at 29,75 inches.

" 113 feet above the level of the ſea, in the temperature of " 60°, and the barometer at 30 inches, is = 59,89358 inches of the parliamentary ſtandard; from whence all the " meaſures of ſuperficies and capacity are deducible."

" That agreeably to the ſame ſcale of inches, a cubic " inch of pure diſtilled water, when the barometer is at " 29,74 inches, and thermometer at 66°, weighs 252,422 " parliamentary grains; from whence all the other weights " may be derived."

CHAPTER IV.

OF THE ACTIONS OF NON-ELASTIC FLUIDS IN MOTION.

HITHERTO we have explained the equilibrium of fluids, or the properties of fluids in a quieſcent ſtate. It is now neceſſary to examine the laws which relate to the ſame when in motion.

Fluids, like ſolids, are poſſeſſed of the general properties of matter, ſuch as have been ſtated and illuſtrated in the firſt part of this work; and amongſt thoſe general properties the *inertia*, and the *force of gravity* have been ſhewn to form the foundation of the doctrine of motion. It has been obſerved that in practical caſes the theoretical laws of motion cannot be verified to a great degree of exactneſs, on account of the fluctuating reſiſtance of the air, and of the friction between the various moving parts of contiguous bodies. But beſides theſe, fluids are obſtructed in their motions by the attraction, adheſion, or viſcidity, amongſt their own particles; by their adheſion or attraction to other bodies, and likewiſe by ſome other circumſtances which have not yet been ſufficiently inveſtigated.

The extenſive application of the ſubject, and the imperfect ſtate of knowledge relatively to it, ſug-

ſuggeſt to perſons of ſcience the neceſſity of inſtituting a long and ſerious experimental inveſtigation, which, in addition to the diſcoveries and experiments that have been already made by many able perſons, would much contribute to the advancement of the theory, and would prove very beneficial to mankind in various reſpects, as in the conſtruction of hydraulic machines, conſtruction of ſhips, navigation, &c.

The only plan which we can at preſent adopt, is, to ſtate in a compendious manner the principal propoſitions which relate to the motion of fluids; then to point out ſome of the deviations from the theoretical rules which experience has clearly ſhewn; and, laſtly, to refer the inquiſitive reader to the works of the beſt authors who have written profeſſedly on the ſubject.

Propoſition. I. *The forces of a fluid medium on a plane cutting the direction of its motion with different inclinations ſucceſſively, are as the ſquares of the ſines of thoſe inclinations.*

Let IKCH, fig. 15. Plate X. repreſent a fluid, for inſtance, the water of a river moving from IK towards CH; and let GB repreſent the edge or ſection of a plain ſurface, ſituated in the water, perpendicular to the ſurface of the water, but inclined to the direction of its motion, ſo as to make an angle DBG with it, which is called *the angle of incidence*, or of *inclination*.

Draw

Draw the quadrantal arch ABF, make AG perpendicular to the direction of the fluid, and from B drop BD perpendicular to AG. Then AG, or its equal GB is the radius, and GD is the ſine of the angle of inclination DBG. Now we have to prove that the force of the moving fluid upon the plane is as the ſquare of the ſine DG; viz. that if, in the ſituation which is repreſented by the figure, the ſine or line GD meaſure four feet, and the preſſure of the water upon the plane be equivalent to 21$\frac{1}{3}$ pounds; then, when the plane is ſituated at another inclination GT, where the ſine GS meaſures 3 feet, the preſſure of the water upon the plane will be equivalent to 12 pounds; for the ſquare of 4 is 16, the ſquare of 3 is 9, and 16 is to 9 as 21$\frac{1}{3}$ is to 12. Alſo when the plane lies in the ſituation GF, which is in the direction of the motion of the fluid, then the preſſure upon it vaniſhes, or becomes equal to nothing.

In order to prove this propoſition it muſt be recollected, that, according to the laws of oblique impulſes, the force is to the effect as radius is to the ſine of inclination, (ſee chap. VIII. of Part I.). Therefore in the preſent caſe, if the ſame quantity of water fell upon the plane in the ſituation AG, as in the ſituation GB, the preſſures upon the plane in thoſe two ſituations would be as AG to GD. But it is evident that in the ſituation AG a greater quantity of the fluid falls upon the plane, than in the ſituation GB; for in the latter ſituation the part

ADBC of the ſtream does not meet the plane: hence it is farther evident that the quanties of water which fall upon the plane in thoſe two ſituations, are as AG to GD, and thoſe different quantities of fluid muſt preſs forward with forces proportionate to their quantities; viz. as AG to GD: but the preſſures on the plane are, on account of the inclinations only, as AG to GD: therefore, in conſequence of both theſe cauſes combined together, the preſſures on the plane in the two ſituations are as AG multiplied by AG, to GD multiplied by GD; viz. as the ſquare of AG (which is the radius, or ſine of the perpendicular direction) to the ſquare of the ſine GD. And the ſame reaſoning is evidently applicable to any other inclination of the plane.

It is alſo evident that the effect or preſſure on the plane is the ſame, whether the plane ſtands ſtill and the fluid moves, or the fluid is at reſt and the plane is moved towards IK in a direction parallel to its original ſituation; viz. with the ſame inclination.

Now in this explanation we have omitted ſeveral interfering circumſtances; we have not taken notice of the particles of water after they have touched the plane; for thoſe particles, after that meeting, muſt go ſomewhere. They cannot return towards IK, for that would be prevented by the current of the fluid; yet they form ſome oppoſition or impediment to the current, and that oppoſition varies according to the velocity of the current, and the inclination of the plane. The water therefore which falls upon the plane muſt flow over the edge of the plane at B, and in a direction which croſſes the original direction of the ſtream, as is indicated by the figure; and it thus forms another impediment to the motion of the ſtream, which contributes to alter the law which is expreſſed in the propoſition. The effect of this laſt ſort of obſtruction is ſubject to very great variations, which depend upon the diſtance of the bottom and ſides of the veſſel, or banks of the river, from the plane; upon the quality of the fluid; but, principally, upon the velocity of the ſtream; for when the ſtream moves with very great velocity, the water, which, after having ſtruck the plane, flows over the edges of it, has no time to go quite behind the plane, but is preſſed forward by the water that follows, and, inſtead of going behind the plane, it tends to carry away, by the adheſion or viſcidity of its parts, the water which it already finds behind the plane, (ſee fig. 16, Plate X.): hence the preſſure on the plane is increaſed conſiderably; becauſe in that caſe, the plane, beſides its being preſſed on one ſide, is alſo ſupported leſs on the other ſide.

We have alſo omitted to take into the account the effect of friction, which ariſes from the adheſion of the water to the plain ſurface, and from the attraction amongſt the particles of the water:

but thoſe cauſes of obſtruction cannot be eaſily ſubjected to calculation, ſince they depend upon other fluctuating cauſes; ſuch as the nature, purity, and temperature of the fluid, the nature of the plane, and the velocity of the motion.—It is in conſequence of this adheſion or friction, that the plane ſuffers ſome degree of preſſure, even when it ſtands in the direction GF, viz. in the direction of the ſtream.

It therefore evidently appears, that the theory of the motion of fluids depends on ſome certain, and upon other fluctuating cauſes, which render the inveſtigation of it extremely difficult and perplexing.

Theſe remarks on the various cauſes which render the reſult of experiments different from the deductions of the theoretical propoſitions, are alſo applicable in a greater or leſs degree to the following proſitions.

Propoſition II. *If the inclination of the plane, in the conſtruction of the preceding propoſition, remain the ſame, and the velocity of the fluid varies, then the preſſure on the plane varies as the ſquare of the velocity.*

Thus, if, when the water moves at the rate of 2 feet per ſecond, the preſſure on a certain fixed plane is equivalent to 10 pounds; then, when the water moves at the rate of 5 feet per ſecond, the preſſure will be equivalent to 62½ pounds; for the ſquare of 2 is 4, the ſquare of 5 is 25, and 4 is to 25, as 10 pounds are to 62½ pounds.

If in equal times the ſame quantity of water ſtruck the plane with different velocities, the preſſures would be as the velocities; viz. a double velocity would produce a double effect, a treble velocity a treble effect; becauſe the momentum is equal to the product of the quantity of matter by the velocity; and, according to this ſuppoſition, the quantity of water is the ſame. But it is evident that when the velocity is double, a double quantity of water will ſtrike againſt the plane in an equal portion of time; hence the preſſure is doubled on account of the velocity, and again doubled on account of the double quantity of water; ſo that upon the whole the preſſure becomes as 2 multiplied by 2, or as the ſquare of 2. — For the ſame reaſon, when the velocity of the water is trebled, the preſſure is as three times 3, or as the ſquare of 3; when the velocity is quadrupled, the preſſure is as the ſquare of four; and, in ſhort, the preſſure on the plane will be as the ſquare of the velocity.

However, on account of the above-mentioned cauſes of obſtruction, this increaſe of preſſure, in proportion to the ſquare of the velocity, is by no means very regular, nor will it proceed beyond a certain limit.

The reſult of this propoſition is evidently the ſame, whether the plane be ſuppoſed to remain fixed

fixed and the fluid to move, or the fluid be ſuppoſed to be at reſt and the plane to be carried through it with the ſame invariable inclination. — The ſame thing muſt likewiſe be underſtood of heavy bodies deſcending in fluids.

Propoſition III. *If planes of different dimenſions move with like inclinations, but with different velocities, and in different fluids; the preſſure upon each plane will be as the product which ariſes by multiplying the ſquare of the velocity by the area of the plane, and by the denſity of the fluid belonging to that plane.*

For it is evident from the preceding Propoſition that when the areas of the planes and the fluids are alike, the preſſures are as the ſquares of the velocities; and it is alſo evident, that, if the ſurface of the plane be doubled, (which makes it equal to twice the original plane,) or trebled, (which makes it equal to thrice the original plane,) &c. the preſſure, or its equal, the ſquare of the velocity will likewiſe be doubled or trebled, &c. Alſo this doubled or trebled ſquare of the velocity muſt be again multiplied by the denſity of the fluid; for a fluid which weighs twice, or three times, or any other number of times, as much as another fluid, muſt produce a double, or treble, or other proportionate, effect.

In practical caſes of this ſort the reſult of experiments has been found to differ conſiderably from the theoretical calculations, which difference is produced by the above-mentioned fluctuating cauſes.

Thus

Thus far we have conſidered the quantity of preſſure which fluids in motion exert upon planes, or planes in motion receive from fluids at reſt. The particulars relative to the effects which are produced by that preſſure, may be eaſily ſuggeſted by the recollection of what has been already ſtated and explained in the firſt part, reſpecting the effects of direct and oblique impulſes; yet it will be of uſe to aſſiſt that recollection, by briefly obſerving, that a body which receives an impreſſion from a fluid, will be driven (or, which is the ſame thing, the body muſt be ſupported) in a direction which is either directly oppoſite, or differently inclined, according as the direction of the preſſure is direct or inclined in a greater or leſs degree.

Thus let ABHI, fig. 1. Plate XI, repreſent a current of water from H to A; let D repreſent the upper edge of a body with a flat ſurface, lying perpendicularly into the water, and held by means of ropes at E. Now in this ſituation, the current will exert its full and direct force againſt the plane ſurface of the body; and if the ropes be let go at E, the body will be driven down by the current, without deviating one way or the other. But if the ſaid body be ſituated in a direction oblique to the ſtream, as at F, and be held by means of ropes at G; the force of the current will drive it againſt the ſide of the river as at K, and a leſſer power will be required at G to prevent the body being driven away with the ſtream. In this caſe the force

force of the ſtream upon the body muſt be reſolved into two forces, viz. LM and MF, the former of which is counteracted by the power at G, whilſt the latter drives the body towards the bank of the river, (ſee chap. VIII. of Part I.). But if, when the body is at F, the ropes be let go at G, then the body will be driven down by the current, nor will it run towards the bank; for in this caſe the body, by moving with the water, will be at reſt relatively to it, and of courſe it will not receive any impreſſion from it.

It is in conſequence of the ſame principle that the ſhip AB, fig. 2. Plate XI. is impelled in the direction from A towards C, by the wind which blows from W towards H, upon the oblique ſails FG, DE. But in this caſe of a ſhip, it muſt be remarked, that beſides the ſails, the wind blows alſo upon the body of the ſhip, upon the ropes, maſts, &c. which are not oblique to the direction of the wind; in conſequence of which the veſſel is partly impelled towards H; and, in fact, this will be found to move in the line DK, though the direction of the body of the veſſel be always parallel to AB. The diſtance CK, viz. of the place in which the ſhip is actually found after a certain time, from that in which it ought to have been according to its original direction AB, is called the *lee-way*; and this lee-way is proportionately greater, the more the wind is inclined to the ſails.

The

The ſame principle likewiſe explains the action of the rudder in turning the ſhip; for when the ſhip AC, fig. 3. Plate XI. is in motion from A towards C, if the rudder be ſituated in the direction AB, oblique to the keel, the water falling obliquely upon it, impels it towards E, and of courſe the head C of the ſhip will be turned towards D. But when the ſhip is becalmed, the ſetting of the rudder aſlant to the keel will have no power to turn the ſhip, becauſe the ſhip being at reſt with reſpect to the water, no impulſe can take place. (1.)

(1.) The method of eſtimating the force of the wind upon the ſails of a ſhip, or of a windmill; alſo the force of the water upon the rudder of a ſhip in motion, or upon the gates of a lock, or ſluice in a river, &c. is derived from Propoſition II. of this chapter. But this force or preſſure of the wind upon the ſails of a windmill, muſt not be miſtaken for that force which turns the axis of the mill; nor muſt the force of the water upon the rudder of a ſhip be miſtaken for the force which actually compels the ſhip to turn; for the latter is only a part of the former, as will be ſhewn by what follows.

The force of wind, which ſtrikes upon the ſail, to turn the axis of a windmill; or the force of the water which ſtrikes againſt the rudder, to turn the ſhip, is as the product of the coſine multiplied by the ſquare of the ſine of the inclination of the ſail to the wind, or of the rudder to the direction of the water.

Let AB, fig. 4. Plate XI. repreſent the axis of a windmill, and DC one of its ſails, ſituated in the direction EC, inclined

It is in conſequence of the effects which ariſe from the different obliquity of impulſes, that bodies of the ſame weight and bulk, but of different ſhapes, will move through a fluid with more or leſs

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clined to the direction GC of the wind, which is parallel to the axis AB.

Through any point G in the line GC, draw a line GE perpendicular to CE, and through the point E, where GE meets CE, draw EF perpendicular to GC. Then GC is the radius, GE is the ſine, and EC is the coſine of the angle GCE, viz. of the inclination of the ſail to the wind. Therefore, by Propoſition II. of this chapter, the force of the wind upon the ſail, when this is placed directly oppoſite to it, is to the force of the wind upon the ſail, when this is placed in the oblique direction EC to it, as $\overline{GC}|^2$ is to $\overline{GE}|^2$. But the force in the direction GE is reſolved into two forces, viz. EF and GF, the latter of which being parallel to the axis, cannot contribute to turn it round; but the force FE, being perpendicular thereto, is employed entirely in turning the axis or the ſail round. Now the force GE : force EF : : GC : CE ; therefore $EF = \frac{GE \times CE}{GC}$.

Hence $GE : EF :: GE : \frac{GE \times CE}{GC} :: \overline{GE}|^2 : \frac{\overline{GE}|^2 \times CE}{GC}$: : (making the radius GC equal one, or unity) $\overline{GE}|^2 : \overline{GE}|^2 \times EC =$ the coſine multiplied into the ſquare of the ſine of the angle of inclination GCE; which product, therefore, expreſſes that part of the force of the wind upon each ſail of the windmill, which contributes to turn the axis of the mill round.

Since

leſs freedom. Thus it has been calculated, that if a cylinder going in the direction of its axis, and a ſphere of the ſame diameter, move in the ſame fluid with the ſame velocity, the reſiſtance to the motion of the the cylinder will be double to that of

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Since, when the ſine of an angle increaſes, the coſine decreaſes, and *vice verſa*; therefore there is a limit, at which the product of the coſine by the ſquare of the ſine is the greateſt, or maximum. This limit, or this maximum, is eaſily aſcertained by the method of fluxions, and is done in the following manner.

Making the radius $=1$, and putting x for the coſine EC, we have, (Eucl. p. 47. B. I.) $\overline{EG}^2 = 1 - xx$; which multiplied by the coſine x, becomes $x - x^3 =$ to the force of the wind upon each ſail, to turn the axis of the mill. Since the fluxion of a maximum is $=0$; therefore, when $x - x^3$ is a maximum, its fluxion $\dot{x} - 3x^2\dot{x} = 0$; or $\dot{x} = 3x^2\dot{x}$, which divided by $\dot{x}$, becomes $1 = 3x^2$: hence $x^2 = \frac{1}{3}$; and $x = \sqrt{\frac{1}{3}}$. Therefore, working by logarithms, $x = \frac{0 - 0{,}47712125}{2} = -0{,}23856062 = 9{,}76143938$, which is the logarithmic coſine of 54°. 44′. 8″. Therefore the moſt advantageous ſituation of the ſail with reſpect to the direction of the wind, or the ſituation in which the wind has the greateſt power to turn the ſail and the axis of the mill round, is when the direction of the ſail makes an angle GCE of of 54°. 44′. 8″, with the direction GC of the wind.

The ſame ſort of demonſtration is applicable to the power which the impreſſion of the water on the rudder of a ſhip in motion, has to turn the ſhip.

In fig. 5. Plate XI. AD repreſents part of the ſhip, B its of the globe; which principally ariſes from the former preſenting its flat baſe to the fluid; whereas the latter preſents a curve ſurface which receives the fluid obliquely. Bodies of the ſame bulk, but of other different ſhapes, have been likewiſe ſubjected

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its rudder ſituated in the oblique poſition EC. The direction of the water is from G towards C, ſince the veſſel moves in the contrary direction. Therefore the water ſtrikes againſt the rudder at an angle of inclination GCE, which, ſince the keel of the ſhip is parallel to CG, is equal to the angle SEC, which the rudder makes with the keel.

From any point G, in the line CG, drop GE perpendicular to CE, and from E drop EF perpendicular to CG. Then CG is the radius, GE is the ſine, and CE the coſine, of the inclination of the rudder to the keel, or to the direction of the water. Now the direct force of the water, is to its oblique force upon the rudder, as $\overline{CG}^2$ is to $\overline{GE}^2$; the latter of which being reſolved into the two forces EF and GF, it is evident that EF is the only force which can contribute to turn the ſhip; for GF, being parallel to the keel, can have no power upon it. Then GE : EF :: GC : CE; therefore $EF = \frac{GE \times CE}{GC}$; hence GE : EF :: GE : $\frac{GE \times CE}{GC}$ :: $\overline{GE}^2$: $\frac{\overline{GE}^2 \times CE}{GC}$ :: (the radius being $=1$.) $\overline{GE}^2 : \overline{GE}^2 \times CE$; which is exactly the ſame reſult as was obtained above for the ſail of the windmill; and of courſe it admits of the ſame maximum, viz. the action of the water againſt the rudder has the greateſt power of turning the ſhip, when the direction EC of the rudder makes the angle CES with the keel; or, which is the ſame thing, when it makes jected to calculation with reſpect to the reſiſtance which they receive from moving fluids. The ſhape of a body which will move through a fluid with the greateſt freedom poſſible, has alſo been calculated; but the reſults of actual experiments have been found to differ conſiderably from the theoretical determinations; nor can we at preſent form any rules ſufficient to aſcertain thoſe differences, ſince they depend upon a variety of fluctuating, and not, as yet, fully aſcertained cauſes. If the reader be deſirous of examining the ſubject ſtill farther, he may conſult the works that are mentioned in the note *.

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makes the angle E C G with the direction of the water, of 54°. 44′. 8″.

For the ſame reaſons ſuch muſt likewiſe be the angles B E D, A C D, fig. 6. Plate XI. which the gates of the lock C D E make with the ſides of the canal A C B E, in order that they may ſuſtain the greateſt preſſure they are capable of, from the water on the ſide A C D E B.

* Archimedes *de inſidentibus humido*. Mariotte on the motion of water and other fluids. Lamy *de l'equilibre des liqueurs*. Newton's *principia*. Gulielmini's *menſura aquarum fluentium*. Graveſand's phil. Muſſchenbrock's phil. Switzer's hydroſts. Varignon's diſſert. in the Mem. Acad. Scien. The works on fluids of Belidor, Deſoguliers, Clare, Emerſon, Boſſu, D'Alambert, Buat, &c. De Prony's *Architect. Hydraulique*. The report of the committee of the Society for the Improvement of Naval Architecture, London 1794. Venturi's experimental enquiries on the lateral communication of motion in fluids. Phil. Tr. &c.

I ſhall conclude this chapter by an obſervation relative to the ſituation of the floating bodies themſelves.

It is of great conſequence in naval architecture, in navigation, &c. to determine not only the quantity of a given floating body, which will remain immerſed, and that which will remain out of the fluid; but likewiſe the poſition in which that body will place itſelf. The full examination of this ſubject would require a great many more pages than we can conveniently allot to it; we ſhall therefore briefly mention the two general principles only, upon which the ſubject depends *.

1ſt. *A floating body will remain at reſt upon a fluid, with that part of its ſurface downwards which lies neareſt to its centre of gravity*; hence an homogeneous ſphere will remain with that part of its ſurface downwards, with which it happens to be firſt ſituated in the fluid; for the centre of gravity of a ſphere is equally diſtant from every point of the ſurface. And a cylinder will reſt with its axis parallel to the ſurface of the fluid, &c.

2d. *When a body floats upon a fluid, and remains at reſt thereon, then the centre of gravity of the part immerſed will lie perpendicularly under the centre of gravity of the part which remains out of the fluid.*— For if you imagine that the body is divided into

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* See Archimedes' maſterly work, *De Inſidentibus Humido*.

two parts, even with the ſurface of the fluid; it is evident that if the upper part be removed, the lower part will aſcend a little; and on the other hand, if the lower part be removed, the upper will deſcend a little into the fluid; therefore thoſe two endeavours counteract each other. And that they counteract each other in the ſame perpendicular line paſſing through their centres of gravity, is alſo evident; for otherwiſe the upper part would deſcend on one ſide, and the lower would aſcend on the other; that is, the body would not remain at reſt, which is contrary to the ſuppoſition*.

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* Upon this conſideration it may be eaſily conceived that any body, regular or irregular, might remain with that part of its ſurface which is neareſt to its centre of gravity, out of the fluid (contrary to the firſt principle) provided that centre and the centres of gravity of the two parts; viz. of that within, and of that without the fluid, ſtood in the ſame perpendicular line. But the difficulty of placing and of preſerving them in that line is ſo very great, that this caſe may well be reckoned impracticable.

CHAPTER V.

OF THE ATTRACTION OF COHESION, OR CAPILLARY ATTRACTION; AND OF THE ATTRACTION OF AGGREGATION.

BEFORE we proceed any farther in the enumeration of the phenomena which relate to the motion of fluids, it will be neceſſary to lay down the reſults of the principal experiments which have been made concerning the attraction of coheſion, as alſo of aggregation, and to explain them in the beſt manner we are able; for by this means the reader will in ſome meaſure be enabled to comprehend how far theſe attractions are concerned in the movements of fluids, and how it happens that the actual motions of fluids through pipes, channels, holes, &c. are conſiderably different from thoſe which might be derived from the general theory of motion.

The attraction of aggregation, is that which takes place amongſt the homogeneous particles of the ſame ſort of ſubſtance; and the attraction of coheſion, is that which takes place between the particles of heterogeneous bodies. See the latter part of chap. I. and the beginning of chap. II. of the preſent part. —The principal facts which have been obſerved relatively to thoſe attractions, are as follows.

I. *The particles of water attract each other.*

The globular form of the drops of rain; the running of two drops of water into each other, when they are

are laid ſo near as to touch, and a variety of other phenomena, render this attraction very manifeſt.

II. *There is an attraction between water and glaſs, which is increaſed by cold, and diminiſhed by heat; but is, cæteris paribus, proportionate to the quantity of the ſurface of contact.*

If the breath from the mouth be thrown upon a glaſs plate, it will be found to adhere to it longer in cold, than in hot, weather.

If a drop of water be laid upon glaſs, it will preſerve a convex ſurface on the ſide fartheſt from the glaſs, but on the neareſt ſide it will adapt itſelf to the ſurface of the glaſs, and will adhere to it with a certain degree of force; but if the ſame drop be ſpread over the ſurface of the glaſs, it will then loſe its convex ſurface, and will adhere to the glaſs with much greater force, as may be proved by endeavouring to ſhake it off in both caſes. By the diſperſion, the particles of water are placed much farther from each other, hence their mutual attraction is diminiſhed; and on the other hand the attraction between the water and the glaſs is increaſed by having augmented the ſurface of contact.

In either of thoſe caſes the water is attracted by the glaſs on one ſide only. But if another piece of glaſs be placed facing the former, and in contact with the film of water, then the water will be attracted and retained with greater force; and if the water be encompaſſed on every ſide by glaſs, as if it be encloſed in a narrow glaſs tube, then the attraction will be ſtronger ſtill, becauſe the quantity of contact in proportion to the quantity of water, is thereby conſiderably increaſed. By this means the attraction is rendered ſo very manifeſt, that the denomination of *capillary attraction* has been ſuggeſted by this more uſual mode of trying ſuch experiments; which is by means of tubes, whoſe bore is about as fine as a *hair*, which in Latin is called *capillus*.

Put ſome water in a glaſs veſſel, as in fig. 7. Plate XI and near the ſurface of the glaſs the water will be found to riſe a little way, forming a curve, as at A and B.—The like effect will take place if you dip part of a piece of glaſs in water, as at C and D.—This effect may be explained in the following manner.

Let AB, fig. 8. Plate XI. repreſent a ſection of the ſurface of a piece of glaſs, having its lower part immerſed in the water BC. Imagine this ſurface to be divided into a number of indefinitely ſmall parts *a*, *b*, *c*, *d*, &c. Then the part *a*, next to the ſurface of the water B C, will raiſe a quantity of water proportionate to its attractive force; but this quantity of water is thereby brought nearer to the part *b* of the glaſs, and is therefore attracted by it, whilſt another quantity of water takes its place next to *a*. Again, the firſt quantity of water being raiſed to *b*, is brought nearer to the part *c* of the glaſs, hence it is attracted by it, and is raiſed to the place *c*, whilſt the quantity of water at *a* takes its place, and another quantity of water comes to the place *a*, and ſo forth.

In conſequence of this attraction, the water ought to form a film equally thick, or the quadrilateral figure *gbas*, on the ſurface of the glaſs. But it muſt be conſidered, that beſides the attraction towards glaſs, the water is poſſeſſed of the attraction of aggregation; viz. of the attraction of its particles towards each other; in conſequence of which, when the firſt quantity of water has been raiſed to the place *a*, another quantity of water *s* is kept ſuſpended, in conſequence of the attraction of water to water, between the water at *a*, and the water B C. When the glaſs has attracted the water to *b*, the part *s* will be enlarged into *t z*, becauſe the two quantities of water, *a* and *b*, can keep ſuſpended a greater portion of water, than the quantity *a* by itſelf. Thus the water will aſcend along the ſurface of the glaſs, and will remain adhering thereto, in ſuch quantity as to form a counterpoiſe to the attraction of the glaſs; viz. the preſſure of the water thus raiſed, and the attraction between it and the water B C, are all together a counterpoiſe to the attraction of the glaſs.

The real aſcent of the water, which in fig. 8. has been enlarged for the ſake of illuſtration, when the glaſs is either flat, or not much bent, ſeldom exceeds one tenth of an inch. But this altitude is increaſed or diminiſhed by a variety of circumſtances; viz. by the temperature and purity of the water, by the quality of the glaſs, and moſtly by the poliſh and cleanlineſs of its ſurface.

Place a glaſs bubble A (that is, an empty glaſs ball) fig. 16. Plate XI. in a glaſs veſſel not quite full of water. This bubble will float on the ſurface of the water, and it will be found to run ſpontaneouſly towards the ſide of the veſſel, as at B, to which it will adhere with a certain force; provided, however, the bubble, on being laid upon the water, be not ſituated too far from the ſides of the veſſel.

This effect is owing to the attraction of the elevated water on the ſide of the veſſel, and that on the ſurface of the bubble. Thus the water at *i* is attracted both by the water at *s* and by the water at *d*, which tends to bring thoſe three parcels of water together, and of courſe the glaſs bubble alſo, which adheres to the water *d*. And this attraction grows ſtronger and ſtronger in proportion as thoſe points come nearer to one another.

It is for the ſame reaſon that if two glaſs bubbles be placed upon water, at no great diſtance from each other, they will run towards each other, and will adhere with a certain degree of force.

If the glaſs veſſel be filled, ſo that the water may project above the edge of the veſſel, and a glaſs bubble be then laid upon it, as in fig. 17. Plate XI. the bubble will be found to recede from the ſides of the veſſel. In this caſe the elevated water *a*, which is contiguous to the ſide A, is attracted leſs powerfully than the elevated water *b*, by the water of the veſſel; for on account of the convexity at A, the water

water between A and *a*, is not ſo near to the elevation *a*, as an equal ſurface *b* B of water on the other ſide of the bubble, is to the elevation *b*.

III. *The perpendicular riſe of water in glaſs tubes is inverſely as the diameter.*—If glaſs tubes opened at both ends, be immerſed with their lower apertures in water, as in fig. 9. Plate XI. the water will inſtantly riſe ſpontaneouſly into their cavities, and it has been found that it will riſe higher in narrower than in larger tubes, by as much as the diameter of the larger tube exceeds that of the ſmaller; the altitude in a tube of one hundredth part of an inch (viz. 0,01) in diameter, being about 5,3 inches. Therefore in a tube of 0,02 in diameter, the altitude of the water will be the half of 5,3, viz 2,65 inches in diameter. Alſo in a tube, whoſe diameter is 0,1 of an inch (or ten times 0,01) the altitude of the water will be the tenth part of 5,3; viz. 0,53 of an inch; and ſo forth *.

Divers

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* Since the diameters of the tubes are inverſely as the altitudes of the water within their cavities, if you call the diameters D, d, and the altitudes of the water A, a, it will be $D : d :: a : A$; whence $AD = ad$; that is, the product of the diameter by the altitude of the water is always the ſame, or the conſtant quantity 0,053 of an inch; for when the diameter is 0,01 of an inch, the water has been found to riſe in it to the altitude of 5,3 inches; and $5{,}3 \times 0{,}01$ is equal to 0,053.

Therefore,

Divers ingenious perſons who have examined thoſe phenomena of capillary attraction, finding that the bulks of the ſuſpended pillars of water are not proportional to the ſurfaces of glaſs with which they are in contact, have been induced to offer ſtrange hypotheſes, which were neither warranted by analogy, not could they account for the phenomena. Dr. Jurin (Phil. Tranſ. N. 355, and 363) ſuppoſed that the real cauſe of the ſuſpenſion of water in tubes is the attraction of the ſmall annular portion of the inſide of the tube, to which the upper ſurface of the water is contiguous and coheres. Dr. Hamilton (in his Eſſays) ſuppoſes that the pillar of water is ſupported by the attraction of the annulus contiguous to the bottom of the tube.

In my opinion, the attraction in this experiment

Therefore, when you wiſh to know how high will the water riſe in a tube of a given diameter, you need only divide 0,053 by the diameter, and the quotient expreſſes the altitude in inches, very nearly; for this altitude is alſo influenced by the various temperature, by the nature and cleanlineſs of the glaſs, &c.

The ſurface of a cylinder is as the product of the diameter multiplied by the axis (or by the altitude;) but it has been ſhewn above, that in the part of the tube which is occupied by the water, the product of the diameter by the altitude is a conſtant quantity; therefore the ſurface of the glaſs which is in contact with ſuch a pillar of water, is likewiſe a conſtant quantity.

is proportionate to the whole ſurface of the glaſs, which is in contact with the column of water; (for every point or particle of that ſurface is endowed with an equal attractive power) and the preſſure of the ſuſpended water is equivalent to it; or it is a counterpoiſe to it. Without attempting to determine the diſtance from the ſurface of the glaſs to which the attractive power may reach, it is clear that a film of water of a certain thickneſs muſt be within that attractive power all round the inſide ſurface of the tube, as high as the top of the pillar; but the reſt of the water which fills up the cavity of the tube, is attached to that film, and is kept ſuſpended by it, in conſequence of the attraction of water to water; yet the whole column of water is kept up by the attraction of the glaſs, and is a counterpoiſe to that force.

Thus if a piece of iron be ſuſpended to a magnet, in virtue of their mutual attraction, and a piece of lead is faſtened to the iron; it is evident that though the magnet has no attraction whatever towards the lead; yet the piece of lead and iron together are kept up by the attractive force of the magnet, and form a counterpoiſe to it; hence, if the weight of the lead be increaſed beyond a certain degree, the whole will drop off from the magnet.

In the like manner the preſſure of the column of water in the tube is equivalent, or it is a counterpoiſe, to the attractive force of the ſurface of the glaſs;

glaſs, which is in contact with it; and of courſe it is proportionate to that ſurface. But in eſtimating the quantity of that counterpoiſe, or of the preſſure of the column of water, we muſt take, beſides the quantity, the altitude alſo, into the account; becauſe, *cæteris paribus*, fluids preſs in proportion to their perpendicular altitudes; and when the baſe varies, or in different cylindrical pillars, the preſſures are as the products of the quantity of matter by the altitude of each pillar reſpectively. Therefore the preſſure of the pillar of water in a glaſs tube, which is a counterpoiſe to the attraction of the glaſs, is the product of the quantity of water by the altitude; and in cylindrical tubes, this product is always proportional to the ſurface of glaſs in contact with the water *. This may be rendered more intelligible by means of an example.

Let the inſide diameter of a tube BC, fig. 12. Plate XI. be double that of the tube DF; then the pillar of water FE will be two inches high when the pillar AC is one inch high. Since the contents of cylinders of the ſame altitude are as the ſquares of their reſpective diameters, and their ſurfaces are

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* It has been ſhewn in the preceding note, that the ſurface of the glaſs tube which is in contact with the pillar of water, is a conſtant quantity; therefore the product of the quantity of water by the altitude of the pillar, muſt likewiſe be a conſtant quantity; ſince it is as the above-mentioned ſurface.

ſimply as their diameters, it is eaſily calculated that if the quantity of water in the pillar EF weighs 2 grains, that of AC muſt weigh 4 grains, and likewiſe that the ſurface of glaſs in contact with the pillar of water EF, is equal to the ſurface of glaſs which is in contact with the pillar of water AC; whence at firſt ſight it ſhould ſeem that thoſe equal ſurfaces ought to keep ſuſpended equal quantities of water, whereas the quantity of water EF is the half of the quantity of water AC; but the pillar of water EF is as high again as the pillar AC; hence its preſſure which is equal to the product of the quantity of water by the altitude (viz. 2 grains by 2 inches) is equal to the preſſure of the column AC, viz. to the product of 4 grains by one inch.

The above-mentioned phenomena of the attraction of coheſion ſhew, that what has been mentioned in the preceding chapter concerning the riſe of water to the ſame level in different pipes, which communicate together, is not ſtrictly true. Indeed, when the pipes are larger than an inch in diameter, the difference of the altitudes becomes inſenſible. But with narrower pipes of different diameters, the water may be plainly perceived to ſtand higher in the ſmaller than in the larger pipes.

IV. *If a tube conſiſt of two cylinders, viz. of the narrow part* EF, *fig.* 14. *Pl.* XI. *whoſe diameter is equal to that of the tube* AB, *wherein the water would riſe to the height* AB; *and of the larger part* CD, *whoſe diameter is equal*

equal to that of the tube GH, *wherein the water would riſe to the height* GH; *and if this compound tube be placed with the narrow aperture in water, as at* F, *the water will not riſe in it higher than the altitude* GH, *viz. to the ſame altitude to which it would riſe if the tube were an uniform cylinder of the diameter of the large part.*

Here it might be expected that the water would riſe higher than DG; but it muſt be conſidered that though the product of the pillars of water EF by its altitude, is leſs than a juſt counterpoiſe to the attraction of the ſurface EF of the glaſs; yet the overplus of attraction of that ſurface, inſtead of aſſiſting to ſupport the water in CE, will operate in a contrary way; that is, if we reckon the attraction of the ſurface EF equal to 10, and if the preſſure of the pillar of water in it, be equal to 8; then the two remaining parts of attractive power will tend to draw the water from the baſon, as much as from the cavity DE, towards the ſurface EF; ſo that by the addition of the narrow tube EF, the attraction of the larger part DI is diminiſhed; at the ſame time that the water in it is partially ſupported by what may be called its perforated baſe IE.

V. *If a compound tube, conſiſting of a larger part* LN, *fig.* 14. *Plate* XI. *wherein the water would riſe ſpontaneouſly to the altitude* M. *and of a narrower part* OK, *equal in diameter to the tube* AB, *wherein the water would riſe to the height* AB; *be filled with water as high as* K, *and then be placed with the large*

aperture

aperture in water as at N, *the whole quantity of water will remain ſuſpended, filling the whole of the large tube and part of the narrow one. The ſame thing will alſo take place with a veſſel of any ſhape, as* P Q S, *provided its upper part be drawn into a narrow cylinder, equal in diameter to the tube* A B.

In thoſe veſſels the water is ſupported partly by the attraction of coheſion, and partly by the preſſure of the atmoſphere. But not having as yet treated of the preſſure and other properties of the atmoſphere, it will not be poſſible for the novice to underſtand at preſent the action of that preſſure; I ſhall therefore ſubjoin the explanation of the above-mentioned phenomenon in the note, for the immediate peruſal of thoſe readers who are otherwiſe acquainted with the properties of the atmoſphere, or of the novice, on a ſecond peruſal of this work *.

VI. *Water*

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* That this phenomenon is occaſioned in great meaſure by the preſſure of the atmoſphere, is evident from the following obſervations; firſt, becauſe the water will not riſe ſpontaneouſly into the veſſels O N, P S, to the height K and P; and ſecondly, becauſe if thoſe veſſels, full of water as high as P, K, together with the baſon, be placed under the receiver of an air-pump, on exhauſting the receiver of air (viz. on removing the preſſure of the atmoſphere), the water will deſcend in them, and will remain in them only as high as it would aſcend ſpontaneouſly; whereas all the preceding phenomena of capillary attraction, or of attraction of coheſion,

VI. *Water riſes between contiguous glaſs plates, and follows the ſame law as it does with tubes; namely,*

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heſion, and likewiſe all the others which are related in this chapter, will anſwer as well in vacuo as in air; unleſs the contrary be mentioned.

How the water comes to be ſupported in thoſe veſſels, partly by the attraction and partly by the atmoſphere, will be ſhewn by the following example and calculation:

A column of water of about 32 feet perpendicular altitude, is a counterpoiſe to a column of air of the altitude of the whole atmoſphere. Therefore, if the perpendicular height of the water in the veſſel PQS, be one foot, its preſſure will be equal to the 32d part of the preſſure of the atmoſphere; hence the atmoſphere preſſes on the aperture of the tube P, with one 32d part of its power; (ſince the preſſure of the atmoſphere at the aperture QS, which otherwiſe would exactly counteract the preſſure at P, is diminiſhed by the preſſure of the water in the veſſel P Q S;) and unleſs the air comes in at the aperture P, the water will not deſcend in the veſſel. Now let us ſuppoſe that the diameter of the aperture P be 0,004 of an inch; for it muſt be of about that ſize when the perpendicular altitude P Q of the water is one foot. The preſſure of the atmoſphere upon a ſquare inch has been found to be about equal to the weight of 14 pounds, or 224 ounces, or 98056 grains; but the area or aperture P, whoſe diameter is 0,004 of an inch, is 0,00001256 of an inch; therefore, by the rule of proportion, we ſay, as one ſquare inch is to the area 0,00001256; ſo is the preſſure of the atmoſphere upon a ſquare inch (viz. 98056 grains) to the preſſure of the atmoſphere on the area 0,00001256. And multiplying 98056 by 0,00001256, we *namely, the altitudes are inverſely as the diſtances of the plates.*

If the glaſs plates be parallel to each other, and be placed with their lower edges in water, the water will riſe between them, and will remain ſuſpended at a certain height. This height is not ſo great as that of the water in a glaſs tube, whoſe diameter is equal to the diſtance between the two plates; and that for an obvious reaſon; namely, becauſe in the

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we obtain the product 1,23158336, viz. little more than one grain, which is the entire preſſure of the atmoſphere on the ſurface of the water in the tube at P. But it has been ſhewn above, that the atmoſphere preſſes upon that ſurface with only the 32^{d} part of its entire force; therefore we muſt divide 1,23158336 by 32, and the quotient 0,03848698, or $\frac{4}{100}^{\text{dths}}$ of a grain nearly, is the real and actual preſſure of the atmoſphere on the ſurface of the water at P; and this trifling preſſure will be eaſily allowed not to be ſufficient to overcome the attraction between the water and the ſurface of the tube P: hence the water remains ſuſpended in the veſſels P Q S, or O N.

This explanation is corroborated by the following experiment.—Fill the veſſel O N, or P Q S, not entirely, but only up to the height T; which is done by lowering them in the water of the baſon; and in that ſituation touch the aperture O, or P, with a wet finger, ſo as to introduce a little water into it. Then if the veſſel be drawn up, leaving its lower aperture only in the water of the baſon; the column of water T N, or T Q, will remain ſuſpended in it, though there is no communication whatever between the water at T, and the water in the capillary aperture.

tube the water is ſurrounded by glaſs on every ſide; yet the proportion is the ſame, that is, in two or more pairs of glaſs plates, the altitudes of the water are inverſely as the diſtances of the plates; and that for the ſame reaſon as in glaſs tubes. A C D F, and B C D E, fig. 11. Plate XI. repreſent two flat glaſs plates, placed ſo as to form a ſmall angle A C B, and immerſed with their lower edges in water. The water will be found to riſe between them, and to remain ſuſpended in the ſpace E F C D E, the outer edge of which, E F C, being a curve called an *hyperbola*. One extremity of this curve riſes as high as the upper part of the glaſs plates at C, and the other extremity reaches as far as the edges of the glaſſes contiguous to the water of the baſon at F and E.

The water between thoſe plates riſes higher near the ſide C D, and lower at a diſtance from it. In ſhort, at any diſtance from C D, as at *a b*, *c d*, *e f*, the water riſes as high as it would riſe between parallel plates, whoſe diſtance from each other equalled the diſtance between the plates of fig. 11. at any of thoſe particular places. Therefore the altitudes of the water at different diſtances from C D, are inverſely as the diſtances between the two plates at thoſe places (1.)

A B C E,

(1.) In fig. 13. Plate XI. (which repreſents the ſame elevation of water which is repreſented in fig. 11.) any two or more

ABCE, fig. 10. Plate XI. are two flat glaſs plates, forming a ſmall angle with each other, like thoſe of the preceding figure; the lowermoſt of which is placed ſo as to form a ſmall angle with the horizon, having the edge AB a little elevated. Thoſe plates may be kept ſeparate at EC, by the interpoſition of a bit of wax, or other ſmall body.

If a drop of water be introduced between thoſe plates at EC, ſo as to touch both plates, this drop will be ſeen to move ſpontaneouſly towards the upper part of the glaſs plates, as far as the edge AB.—It will enſure the ſucceſs of the experiment, if the inner ſurfaces of the glaſſes be previouſly damped with water.

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more altitudes of water, as ab, and cd, are inverſely as the diſtances bt, di, between the two plates at thoſe places; viz. $ab : cd :: di : bt ::$ (by the ſimilarity of the triangles Dbt, Ddi,) $Dd : Db$; and this is the property of the common hyperbola, whoſe aſymptotes are the edge CD of the glaſſes, and the line DS, where the glaſs plate cuts the ſurface of the water in the veſſel G.

It is evident that the water muſt riſe as high as the apex C whatever be the altitude of the plates, ſince near the edge CD the glaſs plates come infinitely near to each other.

If the glaſs plates, inſtead of being flat, be bent more or leſs, then the edge of the water which riſes between them will not be an hyperbola, but it will vary according to the curvature of the plates. See Ditton's Diſcourſe on the new law of fluids.

The

The drop of water will move towards the edge AB, even againſt the direction of its gravity, becauſe the attraction of the glaſſes towards the drop is ſtronger where the plates are cloſer to each other, as at *d*, than where they are farther aſunder, as at *e*; ſo that the drop at *o* is attracted more powerfully towards *d*, than towards *e*.

If the ſide AB be gradually raiſed higher and higher above the horizon, whilſt the drop is moving; the latter will be ſeen to move ſlower and ſlower towards AB, until at laſt the gravity of the drop balances the attraction of the glaſſes, and the water remains at reſt. After which, if the edge AB be raiſed ſtill higher, the weight of the drop being greater than the attraction of the glaſs, will force it to deſcend towards CE.

The preceding phenomena of attraction take place not only between glaſs and water, but likewiſe between almoſt every fluid and every ſolid; even between fluids and fluids, or ſolids and ſolids. A conſiderable difference is however occaſioned by the different degrees of force with which the particles of each body attract either one another, or thoſe of another body.

Thus the attraction of water to glaſs is greater than the mutual attraction of its own particles; it is alſo greater than that of any other fluid towards glaſs, not excepting even the ſpirituous liquors, which are ſpecifically lighter than water; hence water

riſes

riſes higher in capillary glaſs tubes, than any other liquor.

Mercury on the contrary is poſſeſſed of a much greater degree of attraction amongſt its own particles, than towards glaſs; and it is owing to this that, in certain caſes, there ſeems to be a repulſion between thoſe two ſubſtances.

It is owing to this attraction of coheſion or capillary attraction, that water riſes through the fine veſſels of wood, and aſcends to the tops of the higheſt trees;—that it inſinuates itſelf through the pores of certain ſtones, through ſand, ſugar, ſalt, &c.—and that in damp weather, (when the air depoſites a great deal of water) wood, glue, ropes, linen, paper, parchment, ſalts, &c. imbibe the water, and are thereby ſwelled, moiſtened, ſoftened, and ſome of them actually diſſolved.

It is in conſequence of this attraction that metals in a fluid ſtate riſe and ſpread themſelves between the contiguous ſurfaces of other metals that are in a ſolid ſtate. And this indeed is the foundation of the art of ſoldering metals. Hence alſo mercury readily inſinuates itſelf through the pores of gold and tin; for the particles of mercury attract one another much leſs than they do thoſe of gold or tin.

In ſhort almoſt all the innumerable phenomena that are obſerved in the common proceſſes of nature, in the arts and in chemiſtry, depend upon thoſe two ſorts of attraction, and their various degrees in different bodies. When a metal for inſtance is diſſolved in *aqua fortis*, that effect is owing to the particles of the metal having a greater attraction for thoſe of the *aqua fortis*, than for each other.

For the ſake, however, of diſtinction and perſpicuity, when the attraction between two bodies is not ſo powerful as to occaſion a manifeſt change of nature in either of the bodies, it is called *attraction of coheſion*, and when it produces a change, it is then called *attraction of affinity*, or *ſpecific attraction*.

We ſhall, therefore, treat of the attraction of affinity in other chapters of this work, and ſhall confine the preſent merely to the attractions of coheſion and aggregation.

The explanations of the phenomena, which have been already deſcribed concerning glaſs and water, are ſufficient to illuſtrate, and to account for, thoſe which may be obſerved between other fluids and glaſs, or between other fluids and other ſolids; allowing for the difference which ariſes from their different attractive forces: yet, as quickſilver has a much ſtronger attraction of aggregation than of coheſion to glaſs, it will be proper briefly to deſcribe the principal experiments that have been made with thoſe two ſubſtances; leſt the novice, ſurpriſed by the peculiarity of the phenomena, ſhould be induced to ſuppoſe that a repulſion exiſts between thoſe two ſubſtances.

If a ſmall globule of quickſilver be laid upon clean paper, and a piece of glaſs be brought into contact with it; the mercury will adhere to it, and will be drawn away from the paper. If, whilſt the ſmall globule of quickſilver is thus adhering to the glaſs, a larger quantity of quickſilver be brought in contact with the ſmall globule, the latter will immediately forſake the glaſs, and will incorporate with the other quickſilver; which ſhews the greater degree of attraction between the particles of mercury than between them and glaſs: hence it will be found impracticable to ſpread the quickſilver, like water, over the ſurface of glaſs. The ſmall globule of quickſilver adheres to the glaſs with a little flat ſurface, which renders the ſhape of the mercury not perfectly globular: but this little derangement of ſhape muſt not be conſidered as incompatible with the ſtrong attraction between the particles of the mercury; for though this attraction be greater than the attraction towards the glaſs, yet the latter muſt produce a proportionate effect; hence a ſmall change of ſhape; whereas if water were uſed in lieu of quickſilver, the ſurface of contact would be much greater.

Place a pretty large drop of quickſilver upon clean paper, and let two pieces of glaſs touch it on oppoſite ſides. On drawing the glaſſes gently from each other, the mercury will, in conſequence of its adherence to the glaſſes, be drawn from a circular into an oblong, or oval, ſhape.

If quickſilver be put in a glaſs, or wooden, or earthen veſſel of upwards of an inch in width, the ſurface of the quickſilver will be horizontal towards the middle, but convex towards the ſides. This alſo is the caſe when a pretty large quantity of quickſilver is laid upon a table, or on a piece of paper, or other flat ſurface; the gravity of it then exceeding the attraction of coheſion.

If an iron ball (which will float upon quickſilver) be laid upon it, a depreſſion of the quickſilver will be obſerved all round the ball, as in fig. 18. Plate XI. and the ball will run towards the ſide of the veſſel, provided it be not ſituated too far from it. Alſo, if two ſuch balls be placed upon quickſilver, but not very far aſunder, they will run towards each other. The reaſon of which is, that where the cavities or depreſſions of the quickſilver are joined; that is, either between the ball and the ſide of the veſſel, or between the two balls, there the preſſure of the quickſilver upon the ball, or balls, is diminiſhed by the attraction of the quickſilver below; and of courſe the balls are impelled that way by the ſuperior preſſure on the oppoſite ſides.

If a ſmall tube AB, fig. 19. Plate XI. open at both ends, be partly immerſed in mercury, the mercury will be found to ſtand lower within the tube than in the veſſel; and this depreſſion has been found to be inverſely as the diameters of the tubes.

Thus,

Thus, if two tubes are immerſed in quickſilver, and the diameter of one is double the diameter of the other; then the difference of perpendicular altitudes between the ſurface of the quickſilver in the latter tube and in the baſon, will be double to the like difference with the former tube.

Quickſilver being an opaque body, it will be neceſſary to hold the tube AB near the ſide of the veſſel, which is ſuppoſed to be of glaſs, in order that the depreſſion of the quickſilver within the tube may be perceived.

The ſame thing takes place between parallel glaſs plates; viz. if they be immerſed in quickſilver, that fluid metal will ſtand lower between them than in the reſt of the veſſel; and the depreſſion is likewiſe inverſely as the diſtances between the plates. If the plates be ſituated ſo as to form a ſmall angle; then the quickſilver, riſing leſs near the angular edge than at a diſtance from it, will form a curve*.

If a glaſs plate be laid in an horizontal ſituation, with a largiſh drop of quickſilver near one edge of it, as in fig. 20. Plate XI. which repreſents a ſection of it, and another glaſs plate, AB, be laid ſo as to form a ſmall angle with it, and at the ſame time to compreſs the drop of quickſilver; the latter will be found to move ſpontaneouſly towards O, viz. towards

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* This curve is an hyperbola, whoſe aſymptotes are the perpendicular edge or joining of the glaſſes, and the level of the mercury in the baſon.

the aperture of the angle, in order to recover its nearly globular figure.

If a tube open at both ends, but having its lower end drawn out into a fine capillary aperture, be filled with quickſilver to the altitude of about an inch or two, no mercury will be found to run out of the lower aperture; but if this lower end be ſuffered to touch other mercury, or if, by breaking off part of the ſmall end, the aperture be enlarged, then the quickſilver will readily run out.

Thoſe phenomena with quickſilver are ſo evidently dependent on its having a much greater attraction of aggregation than of coheſion to glaſs; and they are ſo evidently ſimilar, though in a contrary way, to thoſe which take place between water and glaſs, that after the particular explanations which have been given of thoſe with water, it is needleſs to dwell any longer upon thoſe with quickſilver.

Theſe attractions of coheſion and aggregation form a conſiderable impediment to the thorough inveſtigation of the laws of motion with reſpect to fluids, as their influence is far from having been entirely aſcertained. Even the laws of equilibrium are affected by them. Thus it frequently happens, that if two fluids of different ſpecific gravities, like water and ſpirit of wine, be mixed together, they will afterwards remain mixed; whereas the lighter fluid ought to aſcend and to float upon the heavier.

Thus alſo, if a ſmall ſteel needle, clean and dry, be gently laid upon water, the needle, though ſpecifically heavier than water, will be found to float upon

it.

it. This effect is owing to the attraction of the particles of water to each other, which the ſmall weight of the needle is not ſufficient to overcome. The weight of the needle depreſſes the particles of water which are directly under it, and theſe, by their adheſion to the contiguous particles, draw them alſo below the uſual level; and thus a cavity of conſiderable breadth is formed all round the needle, which cavity may be eaſily perceived in a proper light.

This effect has been commonly attributed to a ſuppoſed repulſion between water and ſteel, which is not true; for though the particles of water attract one another with greater force than they do thoſe of ſteel; yet there is a degree of attraction between them and ſteel, which is ſhewn by the adheſion of the drops of water to iron and to ſteel.

If any water happen to get over the floating needle in the abovementioned experiment, then the latter falls immediately to the bottom.

The different degrees of the attraction both of aggregation and of coheſion between the particles of the ſame ſubſtance, or of different ſubſtances, ſeem to form all the immenſe gradation from the moſt fluid to the moſt ſolid body, whether ſimple or compound. The ſtates intermediate between thoſe extremes, are expreſſed by the various names of fluid, clammy, ſoft, glutinous, tenacious, hard, brittle, rigid, &c. But as thoſe names are incapable

pable of any preciſe definitions, their meanings are commonly uſed, and underſtood with conſiderable latitude. The ſtate of a given body in this reſpect is aſcertained, either by obſerving the weight or force which is required to diſunite its parts; or by comparing it with other bodies; as when it is ſaid, that a ruby is ſofter than a diamond, but harder than the hardeſt ſteel, becauſe with it you may ſcratch the ſteel but not the diamond*.

Various experiments have been inſtituted for the purpoſe of determining the force requiſite to

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* In the formation of ſeveral ſtony concretions; in the cryſtallization of ſalts, after having been diſſolved in water; in the cooling of certain metals after fuſion, &c. a regular arrangement of parts is generally obſerved; the particles of bodies ſhewing a tendency to join in a particular way. It has likewiſe been obſerved, that in the formation of ſtony concretions, and in ſome other proceſſes, the ſlower the operation is performed, the harder the bodies are, which reſult therefrom. Now all this has ſuggeſted the ſuppoſition that the particles of the ſame ſort of matter have an attraction towards each other with certain ends, and a repulſion with the oppoſite parts. Hence, when they are placed in ſuch a ſituation as may allow them to follow that natural inclination, viz. when they are rendered fluid by heat, or by ſolution in water, &c. then they adhere to each other with their friendly parts. Alſo when the operation proceeds ſlowly, then the particles have more time to arrange themſelves properly, and conſequently form a harder body, than when the operation proceeds more expeditiouſly. See Higgins on Light.

diſunite ſolids from contiguous fluids, to diſunite ſolids from contiguous ſolids, and to break or to diſunite the continuity of a given ſolid. But the circumſtances of temperature, purity of the bodies, equality of ſize, ſurface, &c. render ſuch experiments ſubject to a conſiderable uncertainty; I ſhall, notwithſtanding, ſubjoin ſome of the leſs equivocal reſults of ſuch experiments. The properties of ſolids do not belong to this part of my work; but thoſe particulars, which relate to their hardneſs and tenacity, could not with propriety be inſerted in any other part of theſe elements.

If from each of two leaden bullets a piece be cut off with a ſharp knife, and if then the two bullets be preſſed with their flat bright ſurfaces againſt each other, (giving them a little twiſt), they ill be found to adhere ſo firmly to each other, that ſometimes the weight of 100 pounds will hardly be ſufficient to ſeparate them. When ſeparated, a conſiderable degree of roughneſs will be found on their ſurfaces*. The beſt way of performing this experiment is repreſented in fig. 21. Plate XI. which ſhews two

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* The adheſion of the two bullets is certainly not owing to the preſſure of the ſurrounding air; for in the firſt place the atmoſpherical preſſure is by no means ſo great as to produce that degree of adheſion between ſuch ſmall ſurfaces; and, in the ſecond place, the two bullets thus prepared are found to adhere about as firmly in vacuo as they do in air.

prepared bullets adhering to each other, and each having a ring or bit of ſtring paſſing through a hole, ſo that one of the rings may be faſtened to a nail, or other ſteady ſupport, whilſt the neceſſary weight may be ſuſpended to the other ring. The flat and ſmooth ſurfaces of other metals, of glaſs, &c. do alſo cohere to each other with conſiderable force; but with ſuch bodies as are not ſo pliable as lead, a certain artifice is required for the purpoſe; namely, the interpoſition of ſome fluid as water, oil, &c. or of ſome ſubſtance which may be applied in a fluid ſtate, though it may afterwards coagulate and grow ſolid, as tallow, wax, or fluid metals.

Two braſs poliſhed flat ſurfaces, 2 inches in diameter, ſmeared over with greaſe, and put together in a pretty hot ſtate, will, when cold, adhere to each other ſo firmly as to require nearly 600 pounds weight to ſeparate them.

Every body knows how firmly two pieces of metal adhere to each other, when they are ſoldered together; that is, joined by the interpoſition of another metal in a fluid ſtate.

It muſt be obſerved, however, that in theſe laſt experiments, where ſomething is interpoſed between the two ſurfaces, the adheſion ſeems to take place, not between the ſurfaces of the two ſolids, ſo much as between each of thoſe ſurfaces and the interpoſed ſubſtance; for, in the firſt place, it ſeems ſtrange that two ſurfaces ſhould have a greater attraction to each other

other when ſomething is interpoſed, than otherwiſe; and ſecondly, it has been found that the degree of adheſion differs according as different ſubſtances, viz. oil, or water, or wax, greaſe, turpentine, &c. are interpoſed between the ſurfaces of the very ſame ſolids.

The adheſion in theſe experiments is partly attributed to the preſſure of the atmoſphere, becauſe ſometimes the adhering plates are ſeparated in an exhauſted receiver. But, on the other hand, it ſeems likely that the ſeparation of ſome of them in the exhauſted receiver is occaſioned rather by the extrication of air from the ſubſtance which is interpoſed, than by the removal of the atmoſpherical preſſure.

The tenacity or ſtrength of different ſubſtances is meaſured by the force which is required to break them. In a temperate degree of heat, it has been found that wires of the following metals, drawn through the ſame hole, one tenth of an inch in diameter, and faſtened with one end to a nail, whilſt weights were ſuſpended to the other, could not be broken by any force leſs than the annexed weights *.

Lead	29¼	Pounds.
Tin	49¼	
Copper	299¼	
Braſs	360	
Silver	370	
Iron	450	
Gold	500	

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* If the metals, inſtead of being formed into wire by being paſſed through a hole, be ſimply caſt in the ſame mould ſucceſſively, and be then broken by means of weights, their tenacity will be found ſomewhat different from the ſtatements of the above table.

A con-

A conſiderable difference in the tenacity of metallic ſubſtances is occaſioned by their purity, temperature, manner of forming them, &c. But with other ſubſtances, the fluctuation of their tenacity is much greater than with metals, as will appear from the following obſervations of Mr. Emerſon.

" A piece of good oak, an inch ſquare, and a " yard long, ſupported at both ends, will bear in " the middle, for a very little time, about 330 " pounds avoirdupoiſe; but will break with more " than that weight. This is at a medium; for " there are ſome pieces that will carry ſomething " more, and others not ſo much. But ſuch a " piece of wood ſhould not, in practice, be truſted " for any length of time with above a third or fourth " part of that weight. For ſince this is the extreme " weight which the beſt wood will bear, that of a " worſe ſort muſt break with it. I have found by " experience, that there is a great deal of difference " in ſtrength, in different pieces of the very ſame " tree; ſome pieces I have found would not bear " half the weight that others would do. The wood " of the boughs and branches is far weaker than " that of the body; the wood of the great limbs is " ſtronger than that of the ſmall ones; and the wood " in the heart of a ſound tree is ſtrongeſt of all. I " have alſo found by experience, that a piece of " timber, which has borne a great weight for a ſmall " time, has broke with a far leſs weight, when left " upon it, for a far longer time. Wood is likewiſe

“ weaker when it is green, and ſtrongeſt when thoroughly dryed, and ſhould be two or three years old at leaſt. If wood happens to be ſappy, it will be weaker upon that account, and will likewiſe decay ſooner. Knots in wood weaken it very much, and this often cauſes it to break where a knot is. Alſo when wood is croſs grained, as it often happens, in ſawing, this will weaken it more or leſs, according as it runs more or leſs acroſs the grain. And I have found by experience, that tough wood croſs the grain, ſuch as elm or aſh, is ſeven, eight, or ten times weaker than ſtraight; and wood that eaſily ſplits, ſuch as fir, is 16, 18, or 20 times weaker. And for common uſe it is hardly poſſible to find wood, but it muſt be ſubject to ſome of theſe things. Beſides, when timber lies long in a building, it is apt to decay, or be worm-eaten, which muſt needs very much impair its ſtrength. From all which it appears, that a large allowance ought to be made for the ſtrength of wood, when applied to any uſe, eſpecially where it is deſigned to continue for a long time.”

“ The proportion of the ſtrength of ſeveral ſorts of wood, and other bodies that I have tried, will appear in the following table:

Box, yew, plum-tree, oak — —	11
Elm, aſh — — — —	8½
Walnut, thorn — — —	7½

Red fir, hollin, elder, plane, crab-tree, apple-tree	7
Beech, cherry-tree, hazle	6⅔
Alder, aſp, birch, white fir, willow or ſaugh	6
Iron	107
Braſs	50
Bone	22
Lead	6½
Fine free-ſtone	1

“ A cylindric rod of good clean fir, of an inch “ circumference, drawn in length, will bear at the “ extremity 400 pounds, and a ſpear of fir 2 inches “ diameter, will bear about ſeven tons; but not “ more.”

“ A rod of good iron of an inch in circumference, “ will bear near 3 tons weight.”

“ A good hempen rope of an inch in circum- “ ference, will bear 1000 pounds at the extre- “ mity.”

“ All this ſuppoſes theſe bodies to be ſound and “ good throughout; but none of theſe ſhould be “ put to bear more than a third or a fourth part “ of that weight, eſpecially for any length of “ time.” *

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* Emerſon's Princip. of Mechan^{s}. ſect. VIII.—See alſo Muſſchenbroek's *Introd. ad Philoſ. Nat. Caput* XXI. *De Coherentia, et Firmitate,* wherein a great many experiments are mentioned relative to the adheſion, ſtrength, tenacity, &c. of various ſubſtances.

The word *ſtrength* has often been indiſcriminately uſed for expreſſing the tenacity, the brittleneſs, or the rigidity of bodies; but thoſe qualities muſt be duly diſtinguiſhed from each other, whenever any of them is to be uſed in mechanics, or in other circumſtances. Thus glaſs may be broken incomparably eaſier than iron, and a glaſs rod can ſupport a much ſmaller weight than what can be ſupported by an equal iron rod: yet iron may be ſcratched with glaſs, but the latter cannot be ſcratched with the former.

With reſpect to hardneſs, the metals may be placed in the following order, beginning with the hardeſt, and ending with the ſofteſt: iron, platina, copper, ſilver, gold, tin, and lead.

The ſame of the ſemi-metals, as far as it is known. Manganeſe, nickel, biſmuth, tungſten, zinc, antimony, and arſenic.

With reſpect to the difference of elaſticity, the metals ſeem to follow the ſame order as they do with reſpect to hardneſs; except that perhaps copper might be placed before platina.

The rigidity and the elaſticity of metallic ſubſtances, are increaſed by a variety of means, the principal of which are hammering, preſſing, cooling ſuddenly, and mixing ſome of them together in due proportions. And on the other hand, their rigidity and elaſticity are diminiſhed (except when they ariſe from mixture) principally by heating and cooling gradually.

Steel may be rendered harder than any other metallic ſubſtance. Thus if a piece of ſteel be heated red hot, and in that ſtate be plunged in oil, it will thereby become ſo hard, that a file will hardly ſcratch it; and it will be rendered ſtill harder, if inſtead of oil, the red hot ſteel be plunged in water; but if cold mercury be uſed inſtead of either of thoſe liquors, then the ſteel will be rendered ſo hard as to ſcratch glaſs nearly as well as a diamond.

The hardneſs of other natural ſolids, beſides the metals, differs conſiderably, according to the ſtate of purity and of various other circumſtances. However, a uſeful gradation of the principal natural ſolids, with reſpect to hardneſs, is exhibited in the following liſt, which begins with the hardeſt and ends with the ſofteſt.

Diamond, from Ormos.
Pink, bluiſh, or yellowiſh, diamond.
Cubic diamond.
Pale blue ſapphire.
Ruby.
Pale ruby from Brazil.
Deep ſapphire.
Topaz.
Whitiſh topaz.
Spinel.
Spathum adamantinum, or the Corundum ſtone.
Garnet.
Emerald.
Agate.
Onyx.
Sardonyx
Amethyſt
Mineral, or rock cryſtal.
Cornelian.
Green jaſper.
Shoerl.
Tourmaline.
Iceland agate.
Quartz.
Opal.
Chryſolyte.
Reddiſh yellow jaſper.
Zeolyte.
Fluor.
Calcareous ſpar.
Gypſum, and
Chalk.

The reader may naturally inquire whether the attraction of coheſion, and the attraction of aggregation, follow any known law of increaſe or decreaſe, in proportion to the diſtance; but his inquiry will not meet with any ſatisfactory information.

The force of gravity has been ſhewn to decreaſe inverſely as the ſquares of the diſtances. But the attraction of coheſion, and that of aggregation, decreaſe much faſter: for inſtance, if a force of a thouſand pounds weight be required to break a certain ſolid, and if then the broken parts be placed contiguous to each other, and ſo cloſely that the eye cannot diſcern the fracture; it will be found that they may be ſeparated with the utmoſt facility.

It has been ſuppoſed, that thoſe attractions decreaſe inverſely as the cubes of the diſtances; but no ſatisfactory experiments have as yet eſtabliſhed this ſuppoſed law.

CHAPTER VI.

OF THE MOTION OF THE WAVES.

THE eſſential facts relative to the attractions of coheſion and of aggregation having been ſtated in the preceding chapter, we muſt now explain the theory of the movements of fluids, to which we ſhall add ſeveral experimental obſervations, and ſhall endeavour to point out the deviations of the reſults of the latter from the determinations of the former.—The ſubject is extenſive, and but imperfectly known. We ſhall therefore adopt conciſeneſs as far as it may be compatible with perſpicuity.

AFGB, fig. 1. Plate XII. is a bent cylindrical tube, whoſe parts AF, BG, are perpendicular to the horizon, and whoſe diameter is too large to be conſiderably affected by capillary attraction. Let ſome fluid, for inſtance water, be put in it; and if this fluid be put in motion, by ſhaking the tube once or twice, and then ſtopping it, the fluid will be found to continue to move ſome time longer; viz. it will be found to aſcend in one leg, and to deſcend in the other leg alternately. Thoſe vibrations, or (as they are otherwiſe called) *librations*, become gradually ſhorter and ſhorter, on account of the friction between the fluid and the tube, until at laſt the

the fluid remains perfectly at reſt. But thoſe vibrations, whether longer or ſhorter, have been found to be performed in equal portions of time; and theſe are equal to the times in which a common pendulum, the length of which is equal to half the length of the fluid ENFGH, performs its ſmalleſt vibrations (1.)

The

(1.) That is, equal to the times in which a cycloidal pendulum, whoſe length is equal to half the length of the fluid ENFGH, performs its vibrations.

When the fluid in one leg ſtands higher than in the other (which is the ſituation actually repreſented in the figure) divide the difference of altitude, E N, into two equal parts at M.—The fluid actuated by its gravity deſcends in the leg A F, whilſt it aſcends in the oppoſite leg B G; and when it reaches the ſame height in both legs, which is at the level of M, it would remain there at reſt; but having acquired a certain velocity by the deſcent, it is thereby enabled to continue its motion, until it riſes as high as the level of E, in the other leg B G, excepting a ſmall deduction that muſt be made on account of the friction. When the fluid has thus aſcended in the leg BG, it will again deſcend in that leg, and will riſe anew in the other, and ſo on; but performing every one of its vibratious a little ſhorter than the preceding one, until its motion is entirely deſtroyed by the friction, adheſion, &c.

The quantity of matter which is moved in this experiment, is all the fluid in the tube. The moving force is the weight of the fluid E N; viz. the double of E M. Now this quantity of fluid, or moving force E N, does evidently

increaſe

The principal uſe we ſhall make of the above deſcribed vibrations of a fluid in the bent tube, is for explaining

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increaſe and decreaſe, as the ſpace which is to be run through by the fluid in order to reach the point of reſt, or level of M; ſince its length is always the double of that ſpace. For inſtance, when the upper part of the fluid is at Z in the leg A F, it muſt ſtand at O in the other leg; then the difference of altitude, or the moving force, is repreſented by Z K, which is the double of Z M; and the ſame thing may be ſaid of any other ſituation of the fluid. But it has been proved (in Prop. X. and XV. of the note N. 1. to chap. X. Part I.) that the vibrations, whether long or ſhort, of a cycloidal pendulum are performed in equal portions of time, for the very ſame reaſon, namely, becauſe the moving force is always proportionate to the arch which ſtands between the point from which the pendulum begins to deſcend in every vibration, and the loweſt point of the arch of vibration. Therefore the ſame reaſoning which demonſtrates this property of the cycloidal pendulum, proves the like property of the fluid moving in the tube A F G B.

Since the moving force is equal to the difference of elevation between the ſurface of the fluid in one leg, and that of the fluid in the other; therefore, when the fluid is all in one leg, the moving force is equal to its entire weight or gravity, which force will enable it to deſcend perpendicularly through a ſpace equal to its whole length in a certain time; and ſince this deſcent is only a long vibration, and all the vibrations have been demonſtrated to be performed in equal times; therefore that alſo is the time in which the fluid will perform each of its vibrations in the tube. But the time in which explaining the motion of the waves, to which they bear a great degree of analogy.

When the ſurface of water is ſmooth and at reſt, if any force (be it the action of the wind, as at ſea, or the fall of a heavy body, &c.) depreſs the ſurface of it in any particular place, as at A, fig. 2 and 3, Plate XII. (the former of thoſe figures exhibiting a ſection, and the latter a perpendicular view of the ſame object) the contiguous water will neceſſarily riſe all round that place, as at B B B; for if a certain quantity of water be depreſſed below the uſual level, an equal quantity muſt riſe in ſome other place above that level, and the water which ſtands cloſeſt to the place of the original impreſſion, will of courſe be moved.

The water which has thus been elevated, deſcends ſoon after in conſequence of its gravity; and by the time it has reached the original level, it will have acquired

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which a cycloidal pendulum performs each of its vibrations is equal to the time that a body would employ in deſcending perpendicularly by the force of gravity through twice the length of the pendulum (ſee the note N. 1. to chap. X. of Part I.); therefore the fluid in the tube A F G H, and a cycloidal pendulum of half the length of the fluid ENFGH, will perform their vibrations in equal times.

If the reader be deſirous of determining the time of vibration of a fluid in a tube which is not of equal diameter, or whoſe legs are not perpendicular to the horizon, he may conſult Newton's Principia, B. II. Prop. 44, 45, 46; Emerſon's Fluxions, Sect. III. Prob. XX. &c.

acquired a degree of velocity ſufficient to carry it lower than that level; therefore it now acts as another original moving force, in conſequence of which the water will be raiſed on both ſides of it, viz. at A, and at CCC, fig. 3 and 4, Plate XII. And for the ſame reaſon, the deſcent of thoſe elevated parts will produce other elevations contiguous to them, as at BB, DD, fig. 2 and 3, and ſo forth. Thus the alternate riſing and falling of the water in ridges will expand all round the original place of motion; but as they recede from that place, ſo the ridges as well as the adjoining hollows, grow ſmaller and ſmaller, until they vaniſh. This diminution of ſize is produced by three cauſes; viz. by the want of perfect freedom of motion amongſt the particles of water, by the reſiſtance of the air, and by the farther ridges being larger in diameter than thoſe which are nearer.

It is likewiſe on account of the friction, or adheſion, amongſt the particles of water, and of the reſiſtance of the air, that in the ſame place the alternate elevations and depreſſions diminiſh gradually, until the water reaſſumes its original tranquillity; unleſs the external impreſſion be renewed or continued.

One of the abovementioned ridges, or elevations, together with one adjoining cavity, is called a *wave*.

The *breadth* of the wave is the part of the horizontal line, which is occupied by a wave; and this is evidently equal to the diſtance between the tops of two contiguous ridges, or between the loweſt points of two contiguous hollows.

A wave is ſaid *to have run its breadth*, when its elevated part is arrived at the place where the elevated part of the next wave ſtood before, or when the elevated part B has moved as far as D; or (the ſituations of two contiguous waves being given) when one of them is arrived at the place of the other; and the time which is employed in this tranſition is called *the time of a wave's motion.*

It muſt not however be imagined that the water is by this means carried progreſſively from A towards B, D, &c. it being only the ſucceſſive riſing and falling, which is communicated from the original centre of motion to the next parts progreſſively. This may be clearly perceived by laying ſmall floating bodies upon the ſurface of the water, for they will be moved up and down, but will not recede from their original places.

Now the alternate riſing of the water in two adjoining places, as at B and C, has been juſtly conſidered as analogous to the vibratory motion of the water in the bent tube, fig. 1. ſo that the diſtance between the upper point of the ridge of a wave and the loweſt part of its hollow, is like the length of the fluid in the tube, fig. 1. the difference at leaſt is not very great. Therefore the wave will perform one vibration, that is, the ridge of it will become the hollow part, and the latter will be elevated, in the

the ſame time that a pendulum of half the length of the wave, (viz. half the length of the ſurface of the water between the upper part of the ridge and the loweſt part of the hollow) will perform one of its leaſt oſcillations. Hence the motion of waves is regular, or the riſings and fallings of the water in the ſame place are performed in equal portions of time, as is the caſe with the fluid in the tube, fig. 1.

But this time of vibration is half the time in which a wave will run its breadth; for in order to run that breadth, the ridge muſt come, not to the place where the next hollow ſtood, but to the place where the next ridge ſtood. Therefore a wave will run its breadth in the ſame time that a pendulum of half its length will perform two of its leaſt vibrations; or to the time in which a pendulum equal to four times that length, (viz. equal to the length of the ſurface BCD) will perform one vibration; ſince the times, in which pendulums of different lengths perform their vibrations, are as the ſquares of their lengths.

When the waves are broad and do not riſe high, then the abovementioned length, BCD, will not differ much from the breadth of the wave; and in that caſe the wave will run its breadth in the ſame time that a pendulum, whoſe length is equal to that breadth, performs one of its vibrations. Hence, if the breadth of a wave be 39,1196 inches*; then

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[*] Such being the length of the pendulum which vibrates ſeconds. See page 196. vol. I.

that wave will move on at the rate of 39,1196 inches per ſecond of time; that is, at the rate of 195 feet per minute, nearly.

It will eaſily be conceived that the waves riſe higher or lower, according to the power of the original moving force; for the more water is diſplaced by that force, the greater quantity of it muſt be elevated above the uſual level; and of courſe the breadth of the waves is likewiſe greater.

It ſeems to be pretty well determined from a variety of experiments and obſervations, that the utmoſt force of the wind cannot penetrate a great way into the water; and that in great ſtorms the water of the ſea is ſlightly agitated at the depth of 20 feet below the uſual level, and probably not moved at all at the depth of 30 feet or five fathoms*. Therefore the actual diſplacing of the water by the wind cannot be ſuppoſed to reach nearly ſo low; hence it ſhould ſeem that the greateſt waves could not be ſo very high as they are often repreſented by accurate and creditable navigators. But it muſt be obſerved that in ſtorms, waves increaſe to an enormous ſize from the accumulation of waves upon waves; for as the wind is continually blowing, its action will raiſe a wave upon another wave, and a third wave upon a ſecond, in the ſame manner as it raiſes a

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* Boyle's works, folio edition, vol. III. Relations about the bottom of the Sea. Sect. III.

wave upon the flat ſurface of the water. In fact, at ſea, a variety of waves of different ſizes are frequently ſeen one upon the other, eſpecially whilſt the wind is actually blowing. And when it blows freſh, the waves, not moving ſufficiently quick, their tops, which are thinner and lighter, are impelled forward, are broken, and turned into a white foam, particles of which, called the *ſpray*, are carried a vaſt way.

Waves are circular, or ſtraight, or otherwiſe bent, according as the original impreſſion is made in a narrow ſpace nearly circular, or in a ſtraight line, or in other configurations. In open ſeas the waves generally are in the ſhape of ſtraight furrows, becauſe the wind blows upon the water in a parallel manner, at leaſt for a long apparent tract.

When the water receives ſeveral impulſes at the ſame time, but in different places, then the waves which proceed from thoſe places muſt neceſſarily croſs each other.—By this croſſing the waves do not diſturb each other; but they follow their proper directions, by paſſing one upon the other. Thus if two ſtones be thrown upon the ſurface of ſtagnant water nearly at the ſame time, but at a little diſtance from each other; the circular waves which proceed from thoſe places will be clearly perceived to croſs each other, and to follow their peculiar courſes. The reaſon of which is, that the ſame cauſe which produces the alternate riſing and falling of the water upon the ſurface of otherwiſe ſtagnant water, muſt operate

operate in the ſame manner, and muſt produce the like effect on the ſurface of another wave.

When a wave meets with an obſtacle which is ſtraight and perpendicular, ſuch as a wall, a ſteep bank, as RS, fig. 3. then the wave is reflected by it, and the ſhape of the reflected or retrograde wave, is the reverſe of what it would have been on the other ſide of the obſtacle, had the obſtacle not exiſted. Thus in fig. 3. the reflected wave *vtv* has the ſame curvature as it would have had at *xyx*, if the obſtacle had not reflected it; for the middle part of the curvature muſt naturally meet the obſtacle, and muſt be reflected by it firſt; ſo that this part will be found at *t*, when the adjoining parts which are reflected after it are at *vv*, &c.—And ſince waves will croſs without obſtructing each other, the reflected waves will proceed from the obſtacle, and will expand all round, &c.

When the bank or obſtacle is inclined to the horizon, as is frequently the caſe on the ſhores of the ſea; then the reflection of the waves is diſturbed, and it is often abſolutely deſtroyed by the friction of the water upon the ground.

If the obſtacle be ſuch as to reflect a part only of the wave, ſuch as a ſtone or a poſt, which is ſurrounded by the water; then the wave will be partly reflected in ſhapes and directions which differ according to the form and ſize of the obſtacle, whilſt the reſt of the wave will proceed in its original direction.

When a hole in an obſtacle permits part only of a wave to go through, as at Z, fig. 3. then circular waves will be formed on the other ſide of the obſtacle, whoſe centre is the hole; for in fact thoſe waves owe their origin to the motion of the water in that place only.

The ſame cauſes which raiſe water into waves, muſt evidently produce the like effect on other fluids, but in different degrees, according as the fluid is more or leſs heavy, as its particles adhere more or leſs forcibly to each other, and probably likewiſe according as there is a greater or leſs degree of attraction between the fluid and the other body, which gives it the impulſe.

When a ſtone or other heavy body is dropped on the ſurface of oil, the waves are not nearly ſo high, nor ſo quick, neither do they ſpread ſo far as the waves of water. This effect is evidently owing to the clammineſs, or great degree of adheſion between the particles of the oil.

If the waves upon oil be attempted to be raiſed by the force of wind, it will be found very difficult to ſucceed even in a moderate degree. This difficulty is in a great meaſure owing to the attraction between the particles of oil; but beſides this, there may be leſs attraction between oil and air, than between the latter and water; for water always contains a certain quantity of air; and if it be deprived of that air by means of boiling or otherwiſe, a ſhort expoſure to the atmoſphere will enable the water to reimbibe it.

It is likewiſe probable, that the ſurface of water, even when ſtagnant, may not be ſo ſmooth as the ſurface of oil; ſo that the wind may more eaſily catch into the inequalities of the former than of the latter.

It is remarkable that the effect of the wind upon water may in a great meaſure be prevented or moderated, by ſpreading a thin film of oil on the ſurface of the water.

No great quantity of oil is required for this purpoſe; for, though oil be very clammy and adheſive to almoſt all other bodies; yet when dropped upon water, it will inſtantly ſpread and extend itſelf over a vaſt ſurface of water; and it will even drive ſmall floating bodies out of its way, acquiring, as it ſeems, a repulſive property amongſt its own particles.

This repulſion may be ſhewn in the following amuſing manner: Cut a light ſhaving of wood, or of paper, in the form of a comma, or of the ſize and ſhape of fig. 5. Plate XII. ſmear it with oil, then place it upon the ſurface of a pretty large piece of ſmooth water; and the bit of wood or paper will be ſeen to turn round in a direction contrary to that of the point A, which is occaſioned by the ſtream of oily particles iſſuing from the point and ſpreading themſelves over the ſurface of the water.—This experiment will not ſucceed in a baſon or other ſmall

veſſel

veſſel full of water, wherein the particles of oil have not room enough to expand themſelves.

If a heavy body be dropped on the ſurface of water which is thus covered with a film of oil, the waves will take place in the ſame manner as if there were no oil. But the blowing of the wind will have little or no effect upon it. In this caſe the oil ſeems to act between water and air, in the ſame manner as it acts between the moving parts of mechanical engines; viz. it lubricates the parts, and renders the motion free and eaſy.

But whether this be the real explanation or not, the fact is not leſs true than ſurpriſing; and a very uſeful conſequence has been derived from it, namely, a method of ſtilling the waves of the ſea in certain caſes.

It is expreſsly mentioned by Plutarch* and Pliny†, that the ſeamen of their times uſed to ſtill the waves in a ſtorm, by pouring oil into the ſea. But ſince the revival of learning, though ſeveral obſervations relative to it are to be found in accounts of voyages, &c. yet I do not know that any notice has been taken of this account by any philoſophical writer, previous to the late celebrated Dr. Franklin, who collected ſeveral accounts relative to the ſubject,

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* Quæſt. Nat.

† Hiſt. Nat. lib. ii. c. 103.

ject, and made a variety of experiments upon it, the ſum of which is as follows *.

A ſmall quantity of oil, for inſtance, a quarter of an ounce, will ſpread itſelf quickly and forcibly upon the water of a pond or lake, to the extent of more than an acre; and if poured on the windward ſide, the water will thereby be rendered quite ſmooth as far as the film of oil extends, whilſt the reſt of the pond may be quite rough, from the action of the wind.

If the oil be poured on the leeward ſide, then the force of the wind will in a great meaſure drive it towards the bank. Beſides which, the experiment is fruſtrated by the waves coming to that ſide already formed; for the principal operation of the oil upon water is, as it ſeems, 1ſt. to prevent the raiſing of new waves by the wind; and 2dly. to prevent its driving thoſe which are already raiſed with ſo much force, as it would if their ſurface were not oiled.

Such experiments at ſea are evidently attended with a great many difficulties; but in particular caſes eſſential advantages may be derived from the uſe of oil, and ſeveral inſtances of its having been

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* See his paper on the ſtilling of waves by means of oil, in the Phil. Tranſactions, vol. LXIV. or in his miſcellaneous papers.

of very great ſervice, are recorded*. "We might," ſays Dr. *Franklin*, "totally ſuppreſs the waves in "any required place, if we could come at the "windward place, where they take their riſe. "This in the ocean can ſeldom if ever be done. "But perhaps ſomething may be done on particu-

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* Mr. Tengnagel, in a letter to Count Bentinck, dated Batavia, January the 5th, 1770, ſays, "Near the Iſlands Paul and Amſterdam, we met with a ſtorm which had nothing particular in it worthy of being communicated to you, except that the Captain found himſelf obliged, for greater ſafety in wearing the ſhip, to pour oil into the ſea, to prevent the waves breaking over her, which had an excellent effect, and ſucceeded in preſerving us." Phil. Tranſactions, vol. LXIV. page 456.

It has been remarked in Rhode Iſland, that the harbour of Newport is ever ſmooth whilſt any whaling veſſels are in it; which is, in all probability, owing to the fiſh-oil that may come out of them.

It is ſaid to be a practice with the fiſhermen of Liſbon when about to return into the river (if they ſee before them too great a ſurf upon the bar, which they apprehend might fill their boats in paſſing) to empty a bottle or two of oil into the ſea, which will ſuppreſs the breakers, and allow them to paſs ſafely.

In various parts of the coaſt of the Mediterranean, and elſewhere, it is a practice of the fiſhermen, to ſprinkle a little oil upon the water, which ſmooths the ſurface of the water that is ruffled by the wind, and thus enables them to ſee and to ſtrike the fiſh.

“ lar occaſions, to moderate the violence of the “ waves, when we are in the midſt of them, and “ prevent their breaking, where that would be in-“ convenient.

“ For when the wind blows freſh, there are con-“ tinually riſing on the back of every great wave, “ a number of ſmall ones, which roughen its ſur-“ face, and give the wind hold, as it were, to puſh “ it with greater force. This hold is diminiſhed “ by preventing the generation of thoſe ſmall ones. “ And poſſibly too, when a wave's ſurface is oiled, “ the wind, in paſſing over it, may rather in ſome “ degree preſs it down, and contribute to prevent “ its riſing again, inſtead of promoting it.”

Light, volatile, or etherial oils, like ether, ſpirit of turpentine, &c. do not poſſeſs the ſame property as fat oils, ſuch as olive oil, lin-ſeed, rape-ſeed oil, train-oil, &c.

CHAPTER VII.

OF THE MOTION OF FLUIDS THROUGH HOLES, PIPES, CANALS, &C.

THE inſufficiency of the common theory to account for the phenomena which have been obſerved relatively to fluids in motion, ſuggeſts the expedient of ſtating the reſults of the principal and moſt authentic experiments which have hitherto been made in this branch of natural philoſophy; it being from a collection of well eſtabliſhed facts, that a uſeful ſet of theoretical propoſitions, or natural laws, may hereafter be deduced. We ſhall nevertheleſs briefly prefix the leading propoſitions of the common theory, in order that the deviations of its reſults from thoſe of actual experiments, may be rendered more evident to the reader. And in this place it ſeems proper to obſerve, that the imperfections of this theory, which in truth is partly eſtabliſhed upon facts, muſt be attributed not to any deficiency in the mode of reaſoning, but to the want of adequate principles to eſtabliſh that reaſoning upon.—The demonſtration of any propoſition, whether in mathematics or in any other ſubject, does only ſhew the natural, neceſſary, and uncontrovertable dependence of one idea upon the next, throughout the whole chain of ideas, which intervene

vene between the aſſertion of the propoſition, and certain principles or axioms. Therefore the demonſtration may be ſtrictly juſt and proper, yet the propoſition may be either true or falſe, according as the principles upon which it is eſtabliſhed are true or falſe; and according as all the principles upon which that propoſition depends, or ſome of them only, have been taken into the account.

Now with reſpect to the theory of fluids in motion, the defect ariſes from the imperfect knowledge of the principles, or the circumſtances upon which the phenomena depend.

According to the common theory. I. When a fluid is conveyed through a pipe of an uniform bore, or a channel of an uniform ſhape and capacity, as in fig. 6. Plate XII. the velocity of the fluid is the ſame in every ſection of it; viz. in the ſame time an equal quantity of fluid will paſs through AB, or through DC, or through EF, &c. But if the ſaid channel or pipe be narrower at ſome places than at others, then the velocities of the fluid which paſſes through it will be different; viz. at different ſections the velocities will be inverſely as the areas of the ſections. Thus, ſuppoſe that in the channel, fig. 7. Plate XII. the aperture, or the area of the ſection AB, is equal to half the area of the ſection CD; then the velocity of the fluid at AB will be double the velocity of the fluid at CD; for ſince the channel, or pipe, remains always full, it is evident that in the ſame time an equal quantity of fluid muſt paſs through CD, as through AB. But at AB the capacity of the pipe is half that at CD; therefore the fluid muſt move through AB as quick again as it does through CD; ſince, if it moved with the ſame velocity through both places, the quantity of fluid which paſſed through AB in a certain time, would be the half of what paſſed through CD; in which caſe the channel would not remain equally full.

II. If a ſmall aperture be made in the bottom, or in the ſide of a veſſel full of water and open at top; equal quantities of water will flow out of it in equal portions of time, provided the veſſel be kept continually full, by means of a proper ſupply of water. But if the veſſel be not ſupplied with water (in which caſe the quantity of water in it will be gradually diminiſhed, until its ſurface arrives at the aperture); then the water will flow out of the aperture with a velocity which is continually retarded; and which has been found to be nearly equal to the velocity which a body would acquire in falling through a ſpace equal to half the perpendicular altitude of the fluid above the aperture; hence the velocity is as the ſquare root of that altitude. (See what has been ſaid concerning the deſcent of bodies in Chap. V. Part I.)

III. If in the bottoms or in the ſides of equal veſſels containing water, equal apertures be made, but at different diſtances from the ſurface of the water; then the quantities of water which will flow in a given

given time, will be as the ſquare roots of the altitudes of the water above the apertures reſpectively; ſince, by the preceding paragraph, the velocities are in that proportion.

IV. In equal veſſels full of water, if unequal apertures be made at equal diſtances below the ſurface of the water, then the quantities of water which flow in a given time, are nearly as the areas of the apertures. Hence, if cylindric veſſels, full of water, be equal in every reſpect, except their having unequal apertures, the times in which they are emptied will be inverſely as the areas of their apertures; and if they are equal in every other reſpect, except in their diameter, then the times of emptying themſelves will be as their contents reſpectively.

V. Let a veſſel of a cylindric or priſmatic form be ſet up perpendicularly to the horizon, and an aperture be made in its bottom; then if the veſſel be kept conſtantly full by a ſupply of water, twice the quantity of water will flow out of the aperture in the ſame time in which the veſſel would empty itſelf if it were not ſupplied with water.

The demonſtration of thoſe propoſitions might be eaſily derived from the doctrine of motion already explained*: but the determinations of thoſe propoſitions deviate more or leſs from the reſults of actual experiments; and this deviation is owing

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* See D. Bernoulli's and D'Alembert's Theories. Alſo Vince's Hydroſt.

to the following cauſes or concurring circumſtances, which, on account of their uncertain or fluctuating nature, have not yet been ſufficiently inveſtigated.

Theſe are the peculiar natures of fluids, which vary according to the temperature, purity, &c.—the attraction of aggregation, or (as it is otherwiſe called) the *corpuſcular attraction*;—the attraction of coheſion; the friction againſt the ſides of the veſſels; the reſiſtance of the air; the ſize of the veſſel in proportion to the aperture; the ſhape of the aperture; the different directions in which the various parts, or (as they are otherwiſe called) the various *filaments* of the fluid of the ſame veſſel run towards the aperture; and the vortices or irregular motions which are communicated to the fluid by a variety of cauſes; even by an obſtacle to the ſtream at ſome diſtance from the aperture.

Actual experiments accurately performed, and obſervations attentively made on the motion of fluids, have ſhewn the following facts, which for the ſake of perſpicuity we ſhall arrange under three heads; viz. firſt, thoſe which relate to fluids running through open channels; ſecondly, thoſe which relate to the running of fluids out of apertures; and thirdly, thoſe which relate to the jet itſelf out of the aperture.

I. When water runs through a channel of an uniform ſhape, and open at top, as in fig. 6. Plate XII. the water does not move with the ſame velocity throughout the whole capacity or width of the channel; but its motion is ſwifter through the middle of the upper ſurface, than nearer the ſides or the bottom, where its velocity is partly checked by the friction, adheſion, &c.

When the channel is not of an uniform ſhape, or when it is interrupted by obſtacles, the velocities of the water at different tranſverſe ſections are not inverſely as the areas of thoſe ſections; but they differ more or leſs from that ratio, according to the force of the ſtream, and the peculiar configurations of the channel, and the obſtacles which force different parts or filaments of the ſtream to run with different velocities in different directions, which frequently croſs and check each other. Thus in the ſtream, fig. 8. Plate XII. the water in paſſing through the narrow part AB, will move with increaſed velocity, and after having paſſed that part, its momentum will enable it to move on in the ſtraight direction *ed*; but in conſequence of the attraction of water to water, it will drag part of the water at *e* towards *d*, which occaſions a depreſſion of the water about *e*; hence the water from the adjacent parts *f*, *g*, runs to ſupply that defect, and thus a curvilinear or whirling motion *dfge*, is produced.—Theſe whirling motions are called *eddies*.—By this means the velocity of the ſtream, in the direction *ed*, is gradually checked, and its motion is communicated to the contiguous water in the larger part ZR.—Farther on, the greateſt part of the

the ſtream ſtrikes againſt the obſtacle OS, which being aſlant to its direction, deſtroys part of its force. With the other part of that force, (agreeably to the law of the compoſition and reſolution of forces) the water runs in the direction OT, and ſtrikes againſt the bank at T, about which place it meets the other part of the ſtream, which runs in the direction *d*T, and thus by croſſing, they check each other, &c.

The ſame obſervations may be applied to the inequalities of the bottom. Thus, for inſtance, let ABC, fig. 9. Plate XII. repreſent the bottom of a channel which is hollowed at DB. EF repreſents the ſurface of the water. Now the lower part of the ſtream, after having paſſed along the hollow from D to B, will, agreeably to the laws of motion, tend to continue its motion in the laſt direction, viz. in the direction from B towards F; and in fact at F, the ſurface of the water will be ſeen a little elevated above the reſt. In this caſe two portions of the ſame body of water run in different directions, viz. one part from B towards F, and another part from AE towards CF; hence they muſt partly obſtruct each other.

Such eddies and different directions may be clearly obſerved in almoſt any river or natural ſtream of water, eſpecially when the water contains floating particles of earth and other ſolids. By pouring a ſmall quantity of red wine, or of milk, into a baſon full of water, a clear view of thoſe eddies,

eddies, &c. may be exhibited in an eaſy and familiar way. And the experiment may be varied by pouring the milk either in the direction of the ſide, or towards the centre of the baſon; as alſo againſt a ſpoon, which may be made to repreſent an obſtacle either againſt the ſide or at the bottom of the veſſel.

The various changes and other phenomena which take place in rivers, are almoſt all depending upon the directions and the momenta of different parts of the ſtream; ſo that by a thorough examination of the local cauſes which produce them, the methods of uſing them advantageouſly, or of remedying the inconveniencies that ariſe therefrom, may be frequently diſcovered.—This is one of the eſſential advantages which mankind derives from the knowledge of hydroſtatics.

The water which runs in conſequence of its gravity from a higher to a lower part of the ſurface of the earth, in a channel generally open at top, is called a *river*.

A river which flows uniformly and preſerves the ſame height in the ſame place, is ſaid to be *in a permanent ſtate*. But ſuch rivers are ſeldom if ever to be found.

From what has been ſaid above it is evident that the water of a river does not flow with the ſame velocity through the whole width of the river. The line in which the water moves with the greateſt velocity, is called *the Thread of the river*, and this

thread

thread ſeldom lies in the middle of the river, but it generally comes nearer to one ſide than to the other, according to the nature of the impediments, and of the configuration of the banks.

Rivers owe their origin to the natural ſprings, or mountains, or other elevated parts of the ſurface of the earth, whence the water deſcends through ſuch openings as nature, and ſometimes art, offers to it. The waters of various ſprings, by thus running towards the ſame valley, frequently meet and form one ſtream, which, by paſſing continually over the ſame place, hollows the ground and forms itſelf a channel, which, according to the nature and diſpoſition of the ground, goes into various directions, and alters its velocity, but always deſcending from a higher to a lower place, until at laſt it runs either into another river or into the ſea, after having ſometimes paſſed over a tract of ſome thouſands of miles *.

The

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* The proportional lengths of courſe of ſome of the moſt noted rivers in the world are ſhewn nearly by the following numbers.

Mr. Rennell's paper, Phil. Tranſ. vol. 71ſt, p. 90.

European Rivers:

Thames — — —	1
Rhine — — —	5 ¼
Danube — — —	7
Wolga — — —	9½

Aſiatic

The velocity of the water of a river ought to increaſe in proportion as it recedes from its ſource; but the numerous cauſes of retardation, which occur in rivers, are productive of very great irregularities; and it is impoſſible to form any general rules for determining ſuch irregularities.

The unequal quantities of water (ariſing from rains, from the melting of ſnow, &c.) which are conveyed by rivers at different ſeaſons, enlarge or contract their widths, render them more or leſs rapid, and change more or leſs the form of their beds. But independent of this, the ſize and form of a river is liable to be continually altered by the uſual

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Aſiatic Rivers:		
	Indus	5¼
	Euphrates	8½
	Ganges	9½
	Burrampooter	9½
	Nou Kian, or Ava River	9½
	Jenniſea	10
	Oby	10½
	Amoor	11
	Lena	11½
	Hoanho (of China)	13½
	Kian Keu (of ditto)	15½
African River:		
	Nile	12½
American Rivers:		
	Miſſiſipi	8
	Amazons	15¾

uſual flowing of its waters, and by local peculiarities. The water conſtantly corrodes its bed wherever it runs with conſiderable velocity, and rubs off the ſand, or other not very coherent parts. The corroſion is more remarkable in that part of the bottom, which is under the *thread* of the river, or where the water deſcends ſuddenly from an eminence, as in a *caſcade* or *water-fall*. The ſand thus raiſed is depoſited in places where the water ſlacks its velocity, and there by degrees an obſtacle, a bank, and even an iſland, is formed, which in its turn produces other changes. Thus a river ſometimes forms itſelf a new bed, or it overflows the adjacent grounds.

In ſome places we find that an obſtacle, or a bent on one ſide will occaſion a corroſion on the oppoſite bank, by directing the impetus of the ſtream towards that bank. Thus, from divers cauſes, whoſe concurrence in different proportions, and at different times, forms an infinite variety, the velocity of rivers is never ſteady or uniform.

" One of the principal and moſt frequent cauſes," *ſays the very able Profeſſor Venturi*, " of retardation
" in a river, is alſo produced by the eddies which
" are inceſſantly formed in the dilatations of the bed,
" the cavities of the bottom, the inequalities of the
" banks, the flexures or windings of its courſe, the
" currents which croſs each other, and the ſtreams
" which ſtrike each other with different velocities. A
" conſiderable part of the force of the current is thus
" employed

"employed to reſtore an equilibrium of motion, "which that current itſelf does continually de-"range *."

The uſe of rivers is immenſe.—They fertilize the ground;—they ſupply mankind and other animals with water, an article abſolutely neceſſary to life;—they ſerve as tools for a variety of purpoſes, ſuch as for giving motion to mills, pumps, and other engines; they ſerve for conveying the articles of commerce, and for facilitating the intercourſe between inland countries. But I need not enlarge on a ſubject, which is too obvious to need illuſtration, and which in the hands of many able writers, has often been adduced as a proper inſtance of the infinite wiſdom of Providence †.

II. The running of water, or other fluid, out of a veſſel, or reſervoir, through any aperture, is likewiſe influenced by ſome of the above-mentioned cauſes of retardation, as alſo by other peculiar circumſtances.

The ſtream of water which iſſues out of a hole, tends to carry away in its direction any other fluid, or any ſufficiently light ſolids, which may happen to

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[*] Exp. Enquiries on the lateral communication of Motion to Fluids.

[†] For farther information reſpecting rivers, ſee s'Graveſande's Nat. Phil. B. III. chap. x. Rennell's Account of the Ganges, &c. in the Phil. Tranſ. vol. 71ˢᵗ. Guilielmini, della Natura de Fiumi, &c.

be near it. This is what Profeſſor Venturi calls *the lateral communication of motion in fluids.* But by this lateral communication of motion to contiguous bodies, the celerity of the fluid itſelf is checked more or leſs, and its courſe is partly diverted from the courſe which it would otherwiſe follow.

Thus in fig. 10. Plate XII. which repreſents the upper ſurface of two veſſels contiguous to each other, and full of water, as high as the hole or aperture A.—If by pouring more water into the veſſel B, a ſtream of water be cauſed to flow through A, into the veſſel C; this ſtream will carry away the water from the parts *e e*, towards C. But the depreſſion, or deficiency, of water at *e e*, is replaced by the water from the adjacent parts *d d*, which are repleniſhed from the next, and ſo on. This produces eddies at *e d*, *e d*. This phenomenon may be rendered more apparent if a little milk be at times thrown into the veſſel B, or if light and ſmall bodies float on the ſurface of the water.

When a ſtream comes out of a hole, as at A, fig. 11. Plate XII. if a thread, a feather, or other light body be placed very near it, the tendency of the ſtream to carry it away towards B, may be clearly perceived.—The following experiment will ſhew this property in a manner ſtill more convincing.

Let a veſſel be made in the form of the lateral view ADB, fig. 12. Plate XII. viz. open at top,

top, and having one ſlant ſide. Let a cylindrical pipe of about half an inch in diameter, and upwards of a foot long, proceeding from a veſſel C, come ſtraight down into the veſſel A D B, and there let its termination F S, be bent in the direction of the ſlant ſide B D. This done, fill the veſſel A D B with water, then pour water into the veſſel C; ſo that the water running down the pipe E F S, may form the jet S K. It will be found that the water of the veſſel A D B, is carried away by the ſtream, and this veſſel is thereby almoſt entirely emptied.

The ſame communication of motion may be perceived within a tube; as is ſhewn by the following experiment of Profeſſor Venturi.

To an aperture on the ſide of the veſſel A B, fig. 13. Plate XII. a pipe C D, 1,6 inches in diameter, and little more than 5 inches long, was adapted in an horizontal direction. At E, diſtant 0,71 inches from the ſide of the veſſel, a bent glaſs tube E F G, was joined, whoſe cavity was opened into that of the pipe, whilſt its other extremity was immerſed in coloured water, which was contained in a ſmall veſſel G. When by pouring water into the veſſel A B, a ſtream was made to flow out at D, the coloured water was ſeen to riſe conſiderably in the lower leg of the glaſs tube.

This experiment being repeated, when the deſcending leg F G of the glaſs tube was only 6,4 inches longer than the aſcending leg E F. The coloured water of the veſſel G, roſe through the glaſs tube, and

and mixing with the other water, flowed with it out of the pipe at D; and in a ſhort time the veſſel G was emptied.

This ſort of ſuction or communication of motion takes place, whether the diſcharging pipe C D, be directed horizontally, or downwards, or upwards*.

When

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* In a deſcending ſtream this power of communicating motion to the adjacent bodies, is rendered more active by, or rather it may be better explained, on account of, the tendency that a deſcending ſtream has to divide itſelf into ſeparate portions, and of the preſſure of the atmoſphere. This tendency is owing to the acceleration of falling bodies. Suppoſe, for inſtance, that there comes out of a hole at the bottom of a veſſel, an ounce of water per ſecond of time; then, when the firſt ounce has been falling during two ſeconds, it muſt have percurred a ſpace equal to 4 times 16 feet nearly; whereas the ſecond ounce of water having come out one ſecond later, has been falling during one ſecond only, and of courſe it muſt have run through 16 feet only; therefore the diſtance of the firſt ounce of water from the next is equal to 3 times 16 feet.

At the end of three ſeconds, the firſt ounce of water muſt have paſſed along 9 times 16 feet; whilſt the ſecond ounce of water has paſſed along 4 times 16 feet; ſo that the diſtance between the firſt ounce of water and the ſecond, now is 5 times 16 feet; which one ſecond before was only 3 times 16. Therefore the two ounces of water, or any contiguous parts of the deſcending ſtream (for the ſame reaſoning may be evidently applied to any portions, or to the

When water runs out of an aperture on the thin ſide or bottom of a veſſel, as at A, fig. 11. Plate XII. the ſize of the aperture being very ſmall in

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the ſimple particles, of a fluid, and to any portions of time) have a conſtant tendency to ſeparate, and they do actually ſeparate into irregular maſſes, when the ſtream deſcends through a ſufficient ſpace; and at the ſame time the air forces in any contiguous bodies that are ſufficiently moveable, or introduces itſelf between the interſtices, and is driven downwards by the ſucceeding parcels of water.

This is the reaſon which, when a fluid, (ſuch as beer, &c.) is poured out of one veſſel into another in a long ſtream, mixes a conſiderable quantity of air with the liquor, and produces the froth. Upon this principle the machine for blowing the fire of a furnace, by means of a fall of water, is conſtructed, as will be deſcribed in the ſequel.

The reſiſtance of the air, the adheſion of water to water, and the various ſhape of the ſtream, render the ſeparation of its parcels not very regular, and generally ſpread or divide into longitudinal filaments.

The rain-water which in ſome places flows from the tops of houſes through ſpouts, and falls in the ſtreets, in its fall ſeparates into parcels, and ſtrikes the ground with diſtinct blows and ample ſurface.

“I went,” ſays *Profeſſor Venturi*, to the foot of the caſcades “which fall from the glaciere of la Roche-Melon, on the “naked rock at la Novaleſe, towards Mount Cenis, and “found the force of the wind to be ſuch as could ſcarcely “be withſtood. If the caſcade falls into a baſin, the air is “carried to the bottom, whence it riſes with violence, and “diſperſes the water all round in the form of a miſt.”

proportion to the ſide or bottom of the veſſel; the ſtream A B, is not throughout of the ſhape of the aperture, nor is it of an uniform ſize. When the aperture is circular, the diſtance of the narroweſt part of the ſtream, from the inſide ſurface of the veſſel, is about equal to the diameter of the aperture. This narroweſt part of a ſtream has been called *the contracted vein* (*vena contracta* by Newton) from which place forwards the ſtream grows larger, and ſometimes divides itſelf into different parcels.

The diameter of the contracted vein; that is, of the narroweſt part of the ſtream, is ſubject to a little variation; but from a mean of various meaſurements, it appears equal to 81 hundredths of the aperture; ſo that if the diameter of the aperture be one inch, the diameter of the *vena contracta* will be 0,81 of an inch *.

This contraction of the ſtream is undoubtedly owing to the various directions in which the fluid comes along the ſides, and from every part of the veſſel, towards the aperture, as is indicated by fig. 14. Plate XII. and in fact, when the aperture is very large in proportion to the ſize of the veſſel, the contraction of the ſtream is not ſo apparent. Alſo, if the aperture be not in a plate ſufficiently

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* From the meaſurements of Newton, Poleni, Michelotti, Boſſut, and Venturi.

thin,

thin, the *vena contracta* will not be perceived; for ſince the diſtance of that contraction from the inner ſurface of the veſſel is about equal to the diameter of the aperture, if the thickneſs or rather the length of the aperture, exceed its diameter, as when a pipe is added to the aperture; then the contraction, or the tendency to form the contraction, takes place within that thickneſs, or within that length of pipe.

The various filaments of the fluid, which run from every part of the veſſel in oblique directions towards the aperture, partly croſs each other at the *vena contracta*; and this croſſing, or tendency to croſs, is one of the cauſes which enlarge the ſtream beyond that place.

The velocity of the water is not the ſame in every part of the ſtream; for ſince the ſame quantity of water muſt paſs through every tranſverſe ſection of it in a given time, the velocity muſt be inverſely as the area of each tranſverſe ſection. Therefore at the *vena contracta* the velocity is greater than at the aperture. Now it has been found from experiments, that the velocity of the fluid at the aperture, ſuppoſing this to be circular, and to be made in a very thin plate, is very nearly ſuch as a body would acquire by falling perpendicularly from an altitude equal to half the perpendicular height of the fluid in the veſſel, above the centre of the aperture; and that the velocity at the *vena contracta* is ſuch as a body would acquire by falling perpendicularly from that whole height (2.)

If to the circular aperture on the ſide of a veſſel, there be applied a cylindrical pipe of the ſame diameter, and whoſe length is equal to from two to

four

(2.) The velocity of the fluid at the aperture may be deduced from the quantity of fluid which is found upon trial to be diſcharged in a given time; and this is to be done in the following manner.

Call the area of the aperture a; let q repreſent the quantity of fluid which has been diſcharged in the time t, which means the number of ſeconds of time; and let x expreſs the velocity; that is, the ſpace deſcribed in one ſecond of time. Then imagining that all the fluid q is formed into a cylinder, whoſe baſe is a, and height $= h$, we ſhall have $q = ah$; whence $h = \frac{q}{a}$; ſo that the fluid with the firſt velocity x, would have run through the height of the cylinder, viz. through the ſ $\frac{q}{a}$ in the time t. Therefore, $t'' : 1'' :: \frac{q}{a} : \frac{q}{at} =$ the ſpace deſcribed in one ſecond, or x, the velocity ſought.

The proportion between the velocity at the *vena contracta*, and at the aperture, is found by ſaying, as the area of the former is to the area of the latter, ſo is the velocity at the aperture to the velocity at the *vena contracta*; viz. (ſince thoſe areas are nearly ſimilar, and ſimilar areas are to each other as the ſquares of their homologous ſides, or of their diameters) $\overline{0,81}|^2 : \overline{1}|^2 :: 0,6561 : 1 :: 1 : 1,52$, which, the reader is requeſted to obſerve, is nearly the ratio of $1 : \sqrt{2}$; the ſquare root of 2 being 1,414, &c.

four times that diameter, as A B, fig. 15. Plate XII. then a greater quantity of water will be diſcharged through it than through the ſimple aperture in an equal portion of time, every other circumſtance remaining the ſame; the quantities of fluid diſcharged in thoſe two caſes being as 133 to 100 nearly.—The pipe A B, or any other prolongation of whatever ſhape it may be, which is adapted to the aperture of a veſſel, &c. has been called *the adjutage*, probably from its property of promoting the diſcharge of fluid.

It has been alſo obſerved, that the diſcharge in a given time is the ſame, whether the aperture be furniſhed with the above-mentioned cylindric pipe, or with the pipe repreſented in fig. 16. Plate XII. which differs from the former only by its having, cloſe to the ſide of the veſſel, a contraction nearly of the ſhape of the contracted vein.

If the laſt mentioned pipe be cut off at the contraction, and the firſt conical part only be left affixed to the aperture, as in fig. 17. Plate XII. then the diſcharge of water is rather leſs than from a ſimple aperture; but it is probable that it would be quite the ſame, were it poſſible to make the conical adjutage exactly of the ſhape of the natural contracted vein; excepting however the effect of friction.

If to this conical part a cylindrical tube of the diameter of the ſmall part of the conical pipe, be applied, as in fig. 18. Plate XII. the diſcharge of fluid will thereby be diminiſhed, and more ſo according

according as the length of the cylindrical part is increaſed.

If to the ſmall conical part of the adjutage, fig. 17. a diverging pipe, viz. another conical tube be applied, as in fig. 19. Plate XII. the diſcharge of water will thereby be increaſed within a certain limit *. And if between thoſe two conical parts a cylindric tube be interpoſed, as in fig. 20. then the diſcharge is diminiſhed again; but not nearly ſo much as if the outer conical part were removed †.

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* Experience ſhews that the divergency of this termination muſt not be increaſed beyond a certain degree, for in that caſe it will prove rather diſadvantageous than uſeful. It appears that when the divergency is greater than an angle of 16 degrees, the effect ceaſes entirely; and that the greateſt effect takes place; that is, the greateſt quantity of fluid is diſcharged, when the divergency is equal to an angle of about three degrees.

† The effects produced by the above-mentioned adjutages, and the exact quantity of water which is diſcharged through certain apertures, may be derived from the reſults of Profeſſor Venturi's Experiments, which are conciſely ſubjoined.—The meaſures are Engliſh, except the contrary be expreſſed.

The ſame quantity of water (viz. 4 French cubic feet, equal to 4,845 Engliſh cubic feet) flowed out of the ſame veſſel, or reſervoir, which was kept conſtantly full, through the following adjutages, in the annexed times, which are expreſſed in ſeconds. The altitude of the water in the veſſel above

A remarkable advantage is derived from the knowledge of this fact, which is, that when water is conveyed through a ſtraight cylindrical pipe of whatever length it may be, the diſcharge of water may be increaſed by only altering the ſhape of the terminations of that pipe, viz. by making the end of the

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above the level of the centre of the outer aperture of the adjutage was always equal to 32,5 French inches, or 34,642 Engliſh inches.

Through a ſimple circular aperture, in a thin plate, the diameter of the aperture being equal to 1,6 inches, in — —	41″.
Through a cylindrical tube of the ſame diameter as above, and 4,8 inches long. Fig. 15. in	31″.
Through the tube, fig. 16. which differs from the preceding, by having the contraction in the ſhape of the natural contracted vein, in	31″.
Through the ſhort conical adjutage, fig. 17. which is only the firſt conical part of the preceding, in — — —	42″.
Through the pipe, fig. 18. which conſiſts of a cylindrical tube, adapted to the ſmall conical end of fig. 17. and of that diameter, A D being 3,2 inches long, in — —	42″,5.
Through the like adjutage, but longer, A D being 12,8 inches, in — --	45″.
Through the like, ſtill longer, A D being 25,6 inches, in — — —	48″.
Through the adjutage, fig. 22. which conſiſts of the ſimple tube of fig. 15. placed over the conical part of fig. 17. in — —	32″,5.

Through

the pipe, which is cloſe to the reſervoir, or the entrance to it, of the ſhape of the contracted vein, (as at A, fig. 21.) the dimenſions of which have been ſtated in p. 182; and by making the other extremity BC of the pipe, in the ſhape of a truncated cone, whoſe length BC may be equal to nine times the diameter of the cavity at B; and whoſe aperture at C may be larger than the diameter at B, in the ratio of 18 to 10.—By this means the quantity of water which is diſcharged in a given time, will be more than doubled; viz. the quantity of water diſcharged by the ſimple cylindric pipe, is to the quantity of water which is diſcharged by the ſame pipe with the above-mentioned conical terminations, as 10 is to 24 nearly.

The effect of the above-mentioned adjutages is the ſame, whether they be adapted to the ſide or to the bottom of the veſſel, or in any other direction, provided every other circumſtance be the ſame; ſuch as the capacity and form of the reſervoir,

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Through the double cone, fig. 19. the dimenſions of which are, AB = EF = 1,6 inches, AC = 0,977 inches, CD = 1,376 inches, and the length of the outer cone = 4,351 inches, in — — 27″,5.

Through the adjutage, fig. 20. conſiſting of a cylindrical tube 3,2 inches long, and 1,376 inches in diameter, interpoſed between the two conical parts of the preceding, in — 28″,5.

reſervoir, the altitude of the water above the level of the centre of the outer opening of the adjutage, &c.

All flexures, and all ſorts of internal contractions, elongations, enlargements, and projections, of the conducting pipe, diminiſh the quantity of diſcharge more or leſs, according to the number and form of ſuch irregularities, ſharp angular bendings hindering the motion of the fluid, more than thoſe of a regular curvature. The cauſe of this retardation is undoubtedly owing to the eddies, and to the croſſings of the various filaments of the fluid, which, according to what has been ſaid above, muſt neceſſarily take place at thoſe irregularities. This may be rendered ſufficiently evident, if an irregular glaſs pipe be applied to a pretty large veſſel full of water, and with the water there be mixed ſome particles of pounded amber, or other ſubſtance, whoſe ſpecific gravity differs but little from that of water.—All eddies and croſs directions muſt unavoidably deſtroy part of the moving force.

Whenever an irregularity of the ſhape of the aperture, or ſome particular conformation of the veſſel, compel the particles of the fluid to run obliquely towards an aperture, a circular motion is ſoon communicated to the fluid, and an hollow whirl is formed above the aperture. By the circular motion the particles of the fluid acquire a centrifugal force, in conſequence of which they tend to recede from the centre or from the axis of motion, where

where of courſe a hollow is formed, which is larger or ſmaller, according as the rotation of the fluid is more or leſs rapid. When this whirling motion is pretty conſiderable, if any light bodies float upon it, thoſe bodies will be readily drawn downwards towards the aperture; for, ſince the ſpecific gravity of the fluid is greater than that of the bodies, the fluid will acquire a greater degree of centrifugal force, and will recede farther than thoſe bodies from the axis of the whirl. See chap. IX. of Part I.

III. The laws of projectiles, which have been explained at the end of the firſt part of theſe elements, are applicable to fluids as well as to ſolids, excepting ſome peculiarities which are eaſily ſuggeſted by the nature of fluids. Therefore the principal phenomena relative to the direction, and the length of a ſtream of fluid which iſſues out of an aperture, may be determined by the laws of projectiles.

When fluids, like ſolids, are projected in an oblique direction, they deſcribe parabolic paths; for they are at the ſame time acted upon by the projectile force, and by the force of gravity, excepting the deviation from that parabolic curve which is occaſioned by the reſiſtance of the air. But when they are projected perpendicularly upwards or downwards, then they move in ſtraight lines; and yet thoſe ſtraight lines might be conſidered as parabolas grown infinitely narrow.

When a fluid comes out of a hole in the thin ſide of a veſſel, the velocity of projection muſt be reckoned equal to that of the *vena contracta* which is very near the aperture, and not to that of the fluid at the aperture itſelf. Therefore this velocity of projection is as the ſquare root of the perpendicular altitude of the water above the centre of the orifice, (ſee p. 183); whereas the velocity of the aperture itſelf is as the ſquare root of half that altitude: and this ſeems to be ſufficiently warranted by the reſult of experiments.

But when a pipe is adapted to the aperture, then the velocity of projection is not ſo great; for in this caſe there is no contraction of the ſtream.

Independent of this circumſtance, the velocity of projection, and the diſtance to which the jet can reach, are influenced by other circumſtances; viz. 1. By the friction againſt the ſides of the pipe or aperture. 2. By the reſiſtance of the air, in conſequence of which the jet is obſtructed throughout, and is divided at ſome unaſcertainable diſtance from the aperture. 3. By the weight of the fluid itſelf; for when the higheſt particles of a perpendicular jet ceaſe to have motion, as alſo in their deſcent, they preſs upon the aſcending column.

From the friction againſt the ſides of the pipe, and even of the edge of the aperture in a thin plate, various parts of the ſame jet acquire different velocities, but in virtue of the attraction of water to water, and of the lateral communication of motion

tion which ariſes therefrom, the whole jet preſently acquires, and, for a certain length at leaſt, proceeds with the ſame velocity in every part of a tranſverſe ſection. But this velocity is a mean of the different velocities with which the various parts of the jet come out of the aperture; for whilſt the filaments of greater celerity aſſiſt the motion of thoſe which have a leſſer celerity, the latter tend to retard the former: therefore it ſhould ſeem that with a larger aperture, every thing elſe remaining the ſame, the velocity of projection muſt be greater than with a ſmaller aperture; and this is true to a certain degree. But then another circumſtance interferes, which is the reſiſtance of the air; for a larger jet, by preſenting an ampler ſurface to the air, is liable to be divided by it, and by this diviſion the ſurface is increaſed conſiderably, which renders the reſiſtance of the air much greater; that reſiſtance being, *cæteris paribus*, proportionate to the ſurface.

Now all thoſe circumſtances, namely, the friction againſt the ſides of the aperture; the diviſion of the ſtream, which increaſes not only according to the ſize of the jet, but likewiſe according to its initial velocity; and the reſiſtance of the air, are ſo very fluctuating, that it is impoſſible to ſubject them to calculation.

Experience only can inform us of the effects which may be expected in certain circumſtances: yet as the experiments can hardly ever be repeated under the ſame circumſtances preciſely, the laws which are deduced from their general reſults, muſt always be admitted with ſome latitude.

If a veſſel or reſervoir of water be conſtructed ſomewhat like the repreſentation of fig. 22. Pl. XII. and a hole be made in the thin ſide at A, the water which iſſues out of it will aſcend in a perpendicular jet, enlarging and dividing itſelf towards the top; but it will not riſe ſo high as the level of the ſurface B of the water in the veſſel; and it will riſe ſtill leſs high, if a pipe be adapted to the aperture, as in fig. 23. or if a bent pipe proceed from a veſſel, as in fig. 24. which is owing to the above-mentioned cauſes of obſtruction; and in fact by removing thoſe cauſes, at leaſt in part, the height of the jet may be increaſed; obſerving however that it can never be made to equal the height of the water in the reſervoir.

Thus, if the ſpout or aperture be inclined a little, viz. ſo as not to make the jet quite perpendicular, the water will aſcend higher, becauſe in this caſe the deſcending water will not preſs upon the aſcending column.—If a pipe proceed from the veſſel, as in fig. 24. then the pipe ſhould be made large in proportion to the aperture, becauſe in that caſe the water will move very ſlowly through the pipe, in proportion to what it does out of the aperture, and of courſe the friction will be much leſs than if the pipe and the aperture were both of the ſame diameter. It is alſo for the ſame reaſon that the jet will aſcend higher when the conduit pipe is ſhort than when it is long; and that the common figure of the pipes, from which the water ſpouts, which is that of a truncated cone of conſiderable length, will not let the jet aſcend ſo high, nor be ſo uniform and tranſparent, as if a large tube were covered with a flat plate, and a ſmooth hole for the exit of the water were made in the middle of that plate.

By enlarging the aperture, the friction againſt the ſides is diminiſhed; but the friction or oppoſition of the air is increaſed. Therefore as long as the former is diminiſhed faſter than the latter is increaſed, the jet may be made to aſcend higher and higher by enlarging the aperture; but beyond that limit the enlargement of the aperture will not increaſe the height of the jet. Now it has been found from a variety of experiments, that this limit, or maximum of effect, takes place when the diameter of the circular aperture is ſomewhat leſs than an inch and a quarter; ſo that, *cæteris paribus*, the height of the jet will be leſs, when the aperture is either larger or narrower.

With a higher reſervoir full of water, the perpendicular, or the nearly perpendicular, height of the jet is greater than with a lower reſervoir; but this alſo has a limit; and it appears from a variety of experiments, that a jet cannot riſe higher than about 100 feet, be the height of the water in the reſervoir ever ſo great. For the higher the water is in the reſervoir, the greater is the velocity at the aperture;

aperture; and when that velocity has attained a certain degree, the great reſiſtance of the air breaks the ſtream into ſmall drops, which preſent a vaſt ſurface to the air, and are of courſe ſoon checked in their motion *.

If a ſemicircle, as A D M B, fig. 25. Plate XII. be drawn upon the perpendicular ſide A B (as a diameter) of a veſſel A K I B, which is kept conſtantly full of water; and if a hole be made in the thin ſide of the veſſel, as at C; alſo a line, CD be drawn parallel to the horizon from the hole to the ſemicircle; then the fluid which iſſues from the hole C, will form a jet in the parabolic curve CE, and will fall upon the horizontal line B F, at a

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* A Table of the Heights to which jets of little more than an inch in diameter have been found to riſe in a direction nearly perpendicular, when the altitudes of the water in the reſervoirs are from five to 100 feet.

Res.	Jet.	Res.	Jet.	Res.	Jet.	Res.	Jet.	Res.	Jet.
5	4,91	22	20,58	44	38,93	66	55,66	88	71,14
6	5,88	24	22,33	46	40,53	68	57,12	90	72,48
7	6,84	26	24,06	48	42,09	70	58,56	92	73,82
8	7,80	28	25,78	50	43,65	72	60,00	94	75,16
9	8,74	30	27,48	52	45,19	74	61,42	96	76,49
10	9,68	32	29,16	54	46,72	76	62,84	98	77,81
12	11,55	34	30,83	56	48,24	78	64,24	100	79,12
14	13,40	36	32,47	58	49,74	80	65,64		
16	15,22	38	34,11	60	51,24	82	67,02		
18	17,03	40	35,74	62	52,73	84	68,40		
20	18,82	42	37,35	64	54,20	86	69,76		

diſtance BE from the veſſel, which is equal to twice the length of the line CD.—The diſtance BF is called, as in ſolid projectiles, the *amplitude* of the jet.

This however muſt be underſtood for reſervoirs or veſſels of ſmall heights, where the effect of the reſiſtance of the air is inconſiderable; otherwiſe the deviation from the above-mentioned law is great and uncertain (3.)

It evidently follows, that when the hole is made at H, viz. in the middle of the altitude, then the amplitude BF, or the diſtance from the bottom B

(3.) In Prop. 1. of the note to the laſt Chapter of Part I. it has been demonſtrated, that the velocity of a projectile in any point of the parabolic path, is the ſame as it would be acquired by falling perpendicularly along one quarter of the parameter belonging to that point as a vertex. It has alſo been ſhown, that the fluid which comes out of the hole C, deſcribes the parabola CE, and that its velocity at the *vena contracta*, which is very near the aperture, is the ſame as it would acquire by falling perpendicularly from A to C; therefore AC is the fourth part of the parameter which belongs to the vertex C of the parabola CE. Now one of the properties of the parabola is, that the ſquare of its ordinate is equal to the product of the correſponding abſciſſa multiplied by the parameter; therefore $\overline{BE}^2 = 4AC \times CB$; hence $BE = 2\sqrt{AC \times CB}$; and $\frac{1}{2} BE = \sqrt{AC \times CB}$. But by the property of the circle (Eucl. p. 35. Book III.) $\sqrt{AC \times CB} = CD$. Therefore $\frac{1}{2} BE = CD$.—This reaſoning is evidently applicable to any point in the ſide AB.

of the veſſel, where the jet will ſtrike the horizontal plane, is the greateſt poſſible. Alſo that when a hole is made at an equal diſtance from the baſe, as at L, that another hole is from the top of the reſervoir, as at C; the amplitudes will be equal, viz. the jets will ſtrike the horizontal plane in the ſame point E; becauſe in that caſe the line CD is equal to the line LM.

When the initial direction of the jet is neither perpendicular nor parallel, but oblique, to the horizon, then its parabolic path differs in altitude, &c, according to the angle of inclination. But the various particulars which belong to it may be determined from the theory of projectiles, which has been delivered in the laſt chapter of the firſt part of theſe elements; obſerving however that thoſe theoretical reſults are nearly true for ſhort diſtances only; but that when the diſtances, ſize of the jet, &c. are more conſiderable, then nothing but actual experiments can determine the reſult *.

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* For farther particulars relative to the ſubject of this chapter, ſee s'Graveſande's Nat. Phil.; Boſſut's Hydrodyn^{s}.; De Prony's Architect. Hydraulique; Venturi on the lateral communication of motion in fluids; Vince's Hydroſtatics, &c. as alſo moſt of the other works which are mentioned in the note, p. 113. at the end of chap. IV.

CHAPTER VIII.

OF PNEUMATICS, OR PERMANENTLY ELASTIC FLUIDS; OF THE ATMOSPHERICAL AIR; AND OF THE BAROMETER.

THE whole globe of the earth is ſurrounded by, or is involved in, a fluid, called *air*, which though not perceived by our eyes, is, however, manifeſted in various ways. This fluid fills up the ſpace from the ſurface of the earth to the height of ſeveral miles above it, and the whole maſs of it is called the *atmoſphere*.

As fiſhes are ſurrounded by water, and live and move in water, ſo are we human beings, and all other animals, ſurrounded by air, and live and move in air.

A fiſh which is taken out of the water, will die in a ſhort time, and a human being, or any animal taken out of the aërial fluid, will in general die much ſooner.

Water gravitates towards the centre of the earth, and ſo does the air*. Hence, as a fiſh or other body in water is preſſed on every ſide by that fluid, ſo are other animals, &c. preſſed on every ſide by the ſurrounding

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* The preſſure of the air was firſt aſſerted by the Great Galileus, and was ſoon after illuſtrated by his ſcholar Torricellius.

rounding air, and this preſſure (as will be ſhewn in the ſequel) is very conſiderable.

As the progreſſive motion of water from one place towards another, is called a *current* of water; ſo the progreſſive motion of the atmoſpherical air is called in general *wind*, which according to the different velocities of that fluid is more particularly ſpecified by the appellations of *breeze*, *gentle wind*, *gale*, *&c.*

But the particulars in which air principally differs from water, are 1ſt, that air weighs a vaſt deal leſs than water; and 2dly, that water is not compreſſible, whereas a quantity of air may be forced into a ſmaller ſpace, by means of preſſure, or it may be expanded by removing the preſſure; and that expanſibility, as far as we know, may be extended to any degree; nor is it diminiſhed by long continued preſſure.

Air is abſolutely neceſſary to animal life, as alſo to combuſtion, to vegetation, and to other natural proceſſes. In all thoſe proceſſes the air either communicates ſomething to the ſubſtances concerned, or it receives ſomething from them. But this property of receiving or giving is limited; for inſtance, a certain quantity of air is neceſſary for the life of an animal during a given time; now when the animal has lived in it that length of time, the ſame quantity of air will be unfit for the ſupport of the life of that or of any other animal. And the ſame thing muſt be underſtood with reſpect to combuſtion and ſeveral other proceſſes.

Thoſe latter properties of the air are called its *chemical properties*, which will be explained when we come to treat of chemiſtry; whereas its other properties, ſuch as its gravity, compreſſibility, &c. are called its *mechanical properties*, and theſe will be examined in the preſent chapter.

I ſhall juſt mention for the preſent, that beſides the atmoſpherical air, which ſurrounds the earth, there are other permanently elaſtic fluids, the chemical properties of which are eſſentially different from thoſe of air; though their mechanical properties are ſimilar to thoſe of that atmoſpherical fluid; on which account they are all comprehended under the general appellation of *aërial fluids*, or of *permanently elaſtic fluids*; which expreſſion means, that, as far as we know, they are not convertible into a viſible fluid by means either of preſſure or of cold; and thence they are diſtinguiſhed from *vapours*, as from the vapour or *ſteam* of water, which is likewiſe an elaſtic fluid, but not permanently ſo; for either by cooling, or by means of preſſure, that vapour is converted into water.

The principal mechanical properties of air are its weight and elaſticity; but let us begin by manifeſting its exiſtence.

When a perſon blows upon a thread, or duſt, or other light bodies that are placed at a ſhort diſtance from

from his mouth, the light bodies are driven away from their places. Now it is the current of air, that being expelled from the lungs through the mouth, drives the light bodies in its way.

Take a glaſs veſſel, ſuch as a common wine glaſs, turn it upſide down, and holding it in that perpendicular poſition, immerſe it in water, as at A, fig. 1. Plate XIII. it will be found that the water does not enter the glaſs.—That ſubſtance which thus prevents the entrance of the water into the cavity of the glaſs, is a quantity of air. If you incline the glaſs a little, a bubble, viz. a certain quantity of air goes out, and an equal bulk of water takes its place. If the glaſs be inclined ſtill more, all the air will eſcape from it, and the glaſs will be entirely filled with water.—The various parts of this experiment may be explained in a more particular manner; thus, when the glaſs is in the ſituation A, the air in it, being the lighter fluid, is confined by the water which occupies the aperture of the glaſs; but the air being compreſſible, the preſſure of the ſuperincumbent water A B, (p. 31.) forces the air into a narrower ſpace; hence the water will be ſeen to aſcend a little way within the glaſs at B, and the lower you immerſe the glaſs, the higher will the water aſcend within it. When the glaſs is inclined, as at D, the ſurface of the water in it, which remains always horizontal, is *d e*, (p. 28.) and the air occupies the ſpace *c*, the lower part of which is even with the edge *d* of the glaſs. If the glaſs be

inclined

inclined a little more, part of the air is forced out, as is ſhown at M.

The quantity of air which thus eſcapes from the cavity of the glaſs, being preſſed on every ſide by the water, is forced to aſſume a globular form, in which ſhape it is called a *bubble*, which being lighter than an equal bulk of water, aſcends to the ſurface of the latter, where it mixes with the common maſs of atmoſpherical air.

But frequently, when the bubble is ſmall, it remains for a certain time on the ſurface of the water, encloſed in a film or ſhell of water; which is owing to the viſcidity of the water, or to the attraction mutual between the particles of water. In fact, whatever increaſes that viſcidity, ſuch as a ſolution of ſoap, which is frequently practiſed by children, or of any other glutinous matter, will increaſe the durability of the bubbles, and in that caſe, by blowing into the ſolution, the bubbles may be made very large *.

Hence it appears that a bubble of air is not, according to the vulgar idea, an empty ſpace, a mere nothing; but that it conſiſts of a fluid, which,

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* Diſtillers and other perſons that have occaſion to try ſpecimens of ſpirituous liquors, can form a tolerably accurate idea of the ſtrength of thoſe liquors, by ſhaking the bottle, and then obſerving how ſoon the bubbles break on the ſurface of the liquor; for the thinner and purer the ſpirit is, the ſooner will the bubbles break.

though inviſible, has however weight and other qualities; and is, in ſhort, a ſubſtance as much as any other ſubſtance which we feel or taſte *.

When by inclining the above-mentioned glaſs ſufficiently in water, all the air is ſuffered to eſcape from it; then if this glaſs be again turned with its aperture downwards, and in that poſition be drawn upwards, until its aperture remains a little below the

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* The inviſibility of air is what ſuggeſts the vulgar idea of its being nothing. But it muſt be conſidered, that tranſparent bodies, viz. ſuch as let the rays of light paſs freely through them, cannot be ſeen. Thus water, glaſs, air, &c. cannot be perceived by an eye which is entirely ſurrounded by any one of them. And even when that is not the caſe, we can only perceive thoſe ſubſtances by the heterogeneous bodies which they may happen to contain, or by the inflection, refraction, &c. of the rays of light at their ſurfaces; hence, when ſuch bodies are pure, and their ſurfaces are removed from our ſight, ſo that we cannot obſerve the bending of the rays of light at thoſe ſurfaces, then it is impoſſible to diſcern the bodies themſelves.—If a glaſs bottle entirely filled with pure water, be ſituated againſt a dark place, ſo that no objects may be ſeen through it, a perſon who looks directly at it will not be able to ſay whether the bottle be full of water or not.

A fiſh or a man in water, will feel the water, but he cannot ſee it.

The particles which are ſeen moving about when light paſſes through a hole in a room otherwiſe dark, are not the particles of air, but they are particles of duſt, &c. which float in the air.

ſurface of the water in the baſon, as at N, the glaſs will remain entirely full of water; the preſſure of the atmoſphere on the ſurface of the water of the baſon forcing or keeping up the water which fills the glaſs. Nor, in this caſe, can any air enter the cavity of the glaſs, becauſe air being ſpecifically lighter than water, cannot poſſibly deſcend from *d* to *o*, in order to enter that cavity. But if the glaſs be raiſed higher ſtill, ſo that its aperture be elevated above the ſurface of the water in the baſon, then the air will immediately enter on one ſide of the aperture, whilſt the water goes out at the oppoſite ſide.

When the veſſel is ſhort, and its aperture leſs than a quarter of an inch in diameter, the water or other fluid will not eaſily run out of it, though the veſſel be ſituated with the aperture downwards. This is owing to the attraction of aggregation between the particles of water, which will not ſuffer the ſmall quantity of liquor in the neck of the veſſel to be divided ſo as to give room for the entrance of the air: hence it appears why phials with ſmall necks are difficultly filled with any liquor, and difficultly emptied.

A well known experiment, which is frequently ſhewn in a familiar way, depends upon the above-mentioned principle.—A wine glaſs is entirely filled with water or wine; then a flat piece of paper is placed over it, and the palm of the hand is put over the paper. Things being thus prepared, the glaſs with the hand, &c. is turned upſide down, then the hand being gently removed, the glaſs will be found to remain full of water, with the paper adhering to it.

The following experiment is intended to ſhew the ſame property; namely, the preſſure of the atmoſphere in a different and perhaps more ſatisfactory way.

Take a glaſs tube of a pretty uniform bore, and open at both ends, as A B, fig. 2. Plate XIII. fit a cork *d* B to it, and let a ſtick or wire E*d*, be firmly cemented into the cork. In ſhort, form a piſton, like that of a ſyringe, to the glaſs tube. Now place this piſton even with the lower end of the tube, as repreſented at B, in the figure, and in that ſituation place the ſame end of the tube in water, as in fig. 3. and holding the tube ſteadily, pull up the piſton gradually. It will be found that the water follows the cork, and fills up all that part of the tube which is below the piſton, as is ſhewn in fig. 3. By this means the preſſure of the atmoſphere is removed from over that part of the water which is immediately under the tube; therefore the preſſure of the atmoſphere on the reſt of the ſurface of the water in the baſon, forces that water into the tube, filling up its cavity as far as the piſton.

But this preſſure is limited; for if the tube be longer than 33 or 34 feet, and the piſton be pulled up to the higheſt part of it, the water will not riſe higher than about 33 feet, and the reſt of the tube

as

as far as the piſton, will remain without either water or air: therefore the preſſure of the atmoſphere is equal to the preſſure of a perpendicular column of water of the ſame baſe, and about 33 feet in height.

If the ſame experiment be tried with mercury inſtead of water; that is, if the end B of the tube be immerſed in quickſilver, and the piſton be pulled upwards, the quickſilver will be found to riſe not higher than about 29¾ inches; which perpendicular altitude of quickſilver is equivalent to the above-mentioned perpendicular altitude of water; for quickſilver is about 13,6 times heavier than an equal bulk of water; therefore the column of water muſt be 13,6 times as long as the column of quickſilver in order to balance it, or to balance the preſſure of the atmoſphere which is equivalent to it; and in fact, if we multiply 29¾, or 39,75 inches, by 13,6, the product will be 404,6 inches, or little more than 33 feet.

The remainder of the tube between the ſurface of the quickſilver in it and the piſton, when this is pulled higher than the quickſilver will riſe, or the ſpace which remains above the water when the experiment is tried with water, is called a *vacuum*, or empty ſpace; meaning a ſpace void of air, or other ponderous fluid, as far as we know.

The leaſt reflection on the preceding experiments of this chapter, will evidently ſhew, that whether a tube upwards of 30 or 31 inches long, cloſed at one end, be filled with quickſilver, and then be immerſed with its aperture in a baſon of quickſilver*; or a tube opened at both ends be furniſhed with a piſton, and the quickſilver be drawn into it by the pulling up of the piſton; or, laſtly, a tube opened at both ends, have one of its extremity immerſed in quickſilver, and the air be ſucked out of it by means of an engine adapted to its other end; the effect, and the cauſe of that effect, are always the ſame, viz. the quickſilver will riſe to the perpendicular altitude of about 29,75 inches, and will be kept up by the preſſure of the atmoſphere on the ſurface of the quickſilver in the baſon; but in practice the firſt is by far the eaſieſt and moſt effectual way of performing the experiment.

If a glaſs tube, upwards of 31 inches long, be thus filled with quickſilver, and be left undiſturbed with its aperture immerſed in a ſmall baſon of quickſilver, the altitude of the mercury in it will be found to be various, both at different times and at different places. In London its moſt uſual altitude is between 28 and 31 inches; though it is ſeldom to be ſeen below 28,5, or above 30,5 inches. This evidently ſhews that the weight or gravity of the atmoſphere is of a variable nature; and hence the above-mentioned tube filled with quickſilver, &c.

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* A finger muſt be applied to the aperture in turning the tube, which muſt not be removed before that aperture be immerſed into the baſon of mercury.

has

has been called a *barometer* or *baroſcope*, viz. from its property of ſhewing the actual weight of the atmoſphere at any particular place and time *.

No period or regularity has been as yet diſcovered with reſpect to this change of gravity, or to the riſe and fall of the mercury in the barometer, which is equivalent to that preſſure; ſo that it is impoſſible to foretel the altitude of the quickſilver in the barometer for any particular time. But it has been obſerved, that the altitudes of the mercury in the barometer are frequently accompanied with certain ſtates of the weather, ſuch as wind, rain, calms, ſtorms, &c. and frequently alſo a certain altitude of the barometer precedes that particular ſtate of the weather which is uſually connected with it, on which account barometers are often called *weather glaſſes*, and are commonly kept in houſes, on board of ſhips, &c. as indicators of the weather.

The principle upon which thoſe barometers are conſtructed, has already been explained; the other parts which are annexed to the common conſtruction, are either ornamental, or they are intended for the ſecurity of the tube; of the quickſilver in

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* This ſuſpenſion of the quickſilver in the barometer, or inverted glaſs tube, not beyond a certain altitude, and the variations of that altitude, were firſt obſerved by the celebrated Italian philoſopher *Torricelli*; hence the barometer is often called the *torricellian tube*; and the vacuum in the upper part of it, is called the *torricellian vacuum*.

the baſon, &c. they will be particularly deſcribed hereafter. The words which are engraven on the ſcale of inches and tenths, which is annexed to the variable part of the altitude, are expreſſive of the weather, which has been obſerved frequently to accompany thoſe particular altitudes of the mercury. They are as follows:

Inches.	*Words annexed.*
31.	Very dry. Hard froſt.
30,5.	Settled fair. Settled froſt.
30.	Fair. Froſt.
29,5.	Changeable.
29.	Rain. Snow.
28,5.	Much rain. Much ſnow.
28.	Stormy weather.

The riſing and falling of the mercury in the barometer muſt not be conſidered as ſure indications of the weather which is to follow; yet in general they will enable the obſerver to form a pretty good gueſs of the change of weather which may be expected. Numerous obſervations relative to this ſubject have been made in various parts of the world, and, from a collection of thoſe obſervations, the learned Dr. Halley deduced a ſet of rules, which were publiſhed in an early volume of the Philoſophical Tranſactions, and to which not much addition has been made by ſubſequent obſervers.

I ſhall

I ſhall now ſubjoin thoſe rules, or natural laws, together with the conjectures relative to the cauſes upon which they depend, in Dr. Halley's own words.

" To account for the different heights of the mercury at ſeveral times, it will not be unneceſſary to enumerate ſome of the principal obſervations made upon the barometer.

" 1. The firſt is, that in calm weather, when the air is inclined to rain, the mercury is commonly low.

" 2. That in ſerene, good, ſettled weather, the mercury is generally high.

" 3. That upon very great winds, though they be not accompanied with rain, the mercury ſinks loweſt of all, with relation to the point of the compaſs the wind blows upon.

" 4. That, *cæteris paribus*, the greateſt heights of the mercury are found upon eaſterly and northeaſterly winds.

" 5. That in calm froſty weather, the mercury generally ſtands high.

" 6. That after very great ſtorms of wind, when the quickſilver has been low, it generally riſes again very faſt.

" 7. That the more northerly places have greater alterations of the baroſcope than the more ſoutherly.

" 8. That within the tropics, and near them, thoſe accounts we have had from others, and my own

own obſervations at St. Helena make very little or no variation of the height of the mercury in all weathers.

" Hence I conceive that the principal cauſe of the riſe and fall of the mercury, is from the variable winds which are found in the temperate zones, and whoſe great inconſtancy here in England is moſt notorious.

" A ſecond cauſe is the uncertain exhalation and precipitation of the vapours lodging in the air, whereby it comes to be at one time much more crouded than at another, and conſequently heavier; but this latter in a great meaſure depends upon the former. Now from theſe principles I ſhall endeavour to explicate the ſeveral phænomena of the barometer, taking them in the ſame order I laid them down.

" 1. The mercury's being low, inclines it to rain, becauſe the air being light, the vapours are no longer ſupported thereby, being become ſpecifically heavier than the medium wherein they floated; ſo that they deſcend towards the earth; and, in their fall, meeting with other aqueous particles, they incorporate together, and form little drops of rain. But the mercury's being at one time lower than at another, is the effect of two contrary winds blowing from the place where the barometer ſtands, whereby the air of that place is carried both ways from it, and conſequently the incumbent cylinder of air is diminiſhed, and accordingly the mercury ſinks. As for

for inſtance, if in the German ocean it ſhould blow a gale of weſterly wind, and at the ſame time an eaſterly wind in the Iriſh ſea, or if in France it ſhould blow a northerly wind, and in Scotland a ſoutherly, it muſt be granted me that that part of the atmoſphere impendent over England would thereby be exhauſted and attenuated, and the mercury would ſubſide, and the vapours, which before floated in thoſe parts of the air of equal gravity with themſelves, would ſink to the earth.

" 2. The greater height of the barometer is occaſioned by two contrary winds blowing towards the place of obſervation, whereby the air of other places is brought thither and accumulated; ſo that the incumbent cylinder of air being increaſed both in height and weight, the mercury preſſed thereby muſt needs riſe and ſtand high, as long as the winds continue ſo to blow: and then the air being ſpecifically heavier, the vapours are better kept ſuſpended, ſo that they have no inclination to precipitate and fall down in drops; which is the reaſon of the ſerene good weather which attends the greater heights of the mercury.

" 3. The mercury ſinks the loweſt of all by the very rapid motion of the air in ſtorms of wind: for the tract or region of the earth's ſurface, wherein theſe winds rage, not extending all round the globe, that ſtagnant air which is left behind, as likewiſe that on the ſides, cannot come in ſo faſt as to ſupply the evacuation made by ſo ſwift a current; ſo that

that the air muſt neceſſarily be attenuated when and where the ſaid winds continue to blow, and that more or leſs, according to their violence; add to which, that the horizontal motion of the air being ſo quick as it is, may in all probability take off ſome part of the perpendicular preſſure thereof, and the great agitation of its particles is the reaſon why the vapours are diſſipated, and do not condenſe into drops ſo as to form rain; otherwiſe the natural conſequence of the air's rarefaction.

" 4. The mercury ſtands the higheſt upon an eaſterly or north-eaſterly wind, becauſe in the great Atlantic ocean, on this ſide the 35th degree of north latitude, the weſterly and ſouth-weſterly winds blow almoſt always trade; ſo that whenever here the wind comes up at eaſt and north-eaſt, it is ſure to be checked by a contrary gale as ſoon as it reaches the ocean; wherefore, according to what is made out in our ſecond remark, the air muſt needs be heaped over this iſland, and conſequently the mercury muſt ſtand high, as often as theſe winds blow. This holds true in this country, but is not a general rule for others, where the winds are under different circumſtances; and I have ſometimes ſeen the mercury as low as 29 inches upon an eaſterly wind, but then it blew exceeding hard, and ſo comes to be accounted for by what was obſerved upon the third remark.

" 5. In calm froſty weather, the mercury generally ſtands high, becauſe (as I conceive) it ſeldom freezes but when the winds come out of the northern and north-eaſtern quarters; or at leaſt unleſs thoſe winds blow at no great diſtance off; for the northern parts of Germany, Denmark, Sweden, Norway, and all that tract from whence north eaſtern winds come, are ſubject to almoſt continual froſt all the winter; and thereby the lower air is very much condenſed, and in that ſtate is brought hitherwards by thoſe winds; and being accumulated by the oppoſition of the weſterly wind blowing in the ocean, the mercury muſt needs be preſt to a more than ordinary height; and as a concurring cauſe, the ſhrinking of the lower parts of the air into leſſer room by cold, muſt needs cauſe a deſcent of the upper parts of the atmoſphere, to reduce the cavity made by this contraction to an *æquilibrium*.

"6. After great ſtorms of wind, when the mercury has been very low, it generally riſes again very faſt. I once obſerved it to riſe 1½ inch in leſs than ſix hours, after a long continued ſtorm of ſouth-weſt wind. The reaſon is, becauſe the air being very much rarefied by the great evacuations which ſuch continued ſtorms make thereof, the neighbouring air runs in the more ſwiftly to bring it to an *æquilibrium*; as we ſee water runs the faſter for having a great declivity.

"7. The variations are greater in the more northerly places, as at Stockholm greater than at Paris (compared by Mr. Paſcall*); becauſe the

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* *Equilibre des Liqueurs.*

more northerly parts have uſually greater ſtorms of wind than the more ſoutherly, whereby the mercury ſhould ſink lower in that extream; and then the northerly winds bringing the condenſed and ponderous air from the neighbourhood of the pole, and that again being checked by a ſoutherly wind at no great diſtance, and ſo heaped, muſt of neceſſity make the mercury in ſuch caſe ſtand higher in the other extream.

"8. Laſtly, this remark, that there is little or no variation near the equinoctial, as at Barbadoes and St. Helena, does above all others confirm the hypotheſis of the variable winds being the cauſe of theſe variations of the height of the mercury; for in the places above-named, there is always an eaſy gale of wind blowing nearly upon the ſame point, viz. E. N. E. at Barbadoes, and E. S. E. at St. Helena, ſo that there being no contrary currents of the air to exhauſt or accumulate it, the atmoſphere continues much in the ſame ſtate: however, upon hurricanes (the moſt violent ſtorms) the mercury has been obſerved very low, but this is but once in two or three years, and it ſoon recovers its ſettled ſtate of about 29 [illegible] inches.

"The principal objection againſt this doctrine is, that I ſuppoſe the air ſometimes to move from thoſe parts where it is already evacuated below the *æquilibrium*, and ſometimes again towards thoſe parts where it is condenſed and crouded above the mean ſtate, which may be thought contradictory to the

the law of ſtatics, and the rules of the *æquilibrium* of fluids. But thoſe that ſhall conſider how, when once an *impetus* is given to a fluid body, it is capable of mounting above its level, and checking others that have a contrary tendency to deſcend by their own gravity, will no longer regard this as a material obſtacle; but will rather conclude, that the great analogy there is between the riſing and falling of the water upon the flux and reflux of the ſea, and this of accumulating and extenuating the air, is a great argument for the truth of this hypotheſis. For as the ſea over againſt the coaſt of Eſſex riſes and ſwells by the meeting of the two contrary tides of flood, whereof the one comes from the S. W. along the channel of England, and the other from the north, and on the contrary ſinks below its level upon the retreat of the water both ways, in the tide of ebb; ſo it is very probable, that the air may ebb and flow after the ſame manner; but by reaſon of the diverſity of cauſes, whereby the air may be ſet in moving, the times of theſe fluxes and refluxes thereof are purely caſual, and not reducible to any rule, as are the motions of the ſea, depending wholly upon the regular courſe of the moon." So far are Dr. Halley's obſervations.

" It is," ſays *Col. Roy*, " a well known and eſtabliſhed fact, that in the middle latitudes, a north or north-eaſt wind conſtantly raiſes the barometer, and generally higher as its continuance is longer. The contrary happens when a ſouth or ſouth-weſt wind blows; for I believe it is commonly loweſt when the duration and ſtrength of the wind from that quarter have been the greateſt. Thus the north-eaſt wind, by blowing for any length of time, brings into the middle latitudes a maſs of air heavier than that which naturally appertains to the region, and raiſes the barometer above its mean height. The continuance of a ſouth-weſtern carries off the heavy air, depoſits a much lighter body in its ſtead, and never fails to ſink the barometer below its mean height."

The greateſt alterations of the barometer generally take place during clear weather, with a northerly wind; the ſmall changes generally take place during cloudy, rainy, or windy weather, with a ſoutherly wind. The changes of the barometrical altitude are greater in winter than in ſummer; but the mean elevation is greater in ſummer than in winter, and greateſt at the equinox.

The barometer is generally lower at noon and at midnight, than at any other period of the 24 hours.

To thoſe we may add De Luc's obſervation, viz. that a rapid movement of the mercury in the barometer, even when riſing, is an indication of bad weather, but not of long duration.

Such are the indications which may be derived from the movements of the barometer alone; but the obſervers of later times, having made a rational inveſtigation of the poſſible influence of the moon upon

upon the atmoſphere, and upon the weather, have ſhewn that we may form much more probable conjectures relative to the weather, by combining the obſervations of the barometrical movements with the ſituations of the moon *. But of this more in the next chapter.

The movement of the mercury in the barometer about our latitude, has been already ſaid to amount to about 3 inches. But it will be of uſe to know its more ordinary altitude, or its mean altitude.

It appears from the meteorological journals of the Royal Society, which are publiſhed annually in the Philoſophical Tranſactions, that the mean altitude of the barometer is 29,89 inches, and the mean altitude of the barometer for each ſingle year, hardly ever differs from the above, by more than half a tenth of an inch; as appears from the following ſtatement of the mean barometrical altitude of each year, commencing with the year 1787, from which time the barometrical obſervations at the apartments of the Royal Society have been made with great attention and regularity †.

1787.	2 ,80	1792.	29,87	1797.	29,92
1788.	29,96	1793.	29,93	1798.	29,92
1789.	29,79	1794.	29,91	1799.	29,84
1790.	29,98	1795.	29,90	1800.	29,90
1791.	29,87	1796.	29,89		

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* See Toaldo's Syſtem reſpecting the probability of a change of weather, &c. in the *Journal des Sciences Utiles*.

† The mercury in the baſon of the barometer of the Royal

The French reckon the mean altitude of the mercury in the barometer placed on the level of the ſea, equal to 28 French inches, which are equivalent to 29,841 inches Engliſh*.

It appears very clearly, from what has been already ſaid in this chapter, that the air is a ponderous ſubſtance; but the particular weight of a given quantity of air, or its ſpecific gravity, is aſcertained by actually weighing it with a balance. For this purpoſe a glaſs veſſel is weighed firſt full of air, then exhauſted of air, and laſtly, full of water, by which means we obtain the weights of equal bulks of air and of water; and dividing the former by the latter, the quotient will expreſs the ſpecific gravity of the air †. But it muſt be obſerved, that air, being very elaſtic, its bulk, and conſequently its ſpecific gravity, is eaſily increaſed or diminiſhed by heat and cold, as alſo by an alteration of the preſſure; therefore, whenever the ſpecific gravity of an aërial fluid is to be ſtated, it is always proper to ſet down the altitude of the mercury in the barometer, and the degree of heat, at the

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Royal Society at Somerſet Houſe, is ſituated 81 feet above the river Thames, viz. the level of low water ſpring tides. The obſervations are taken twice a day, viz. at 7 or 8 in the morning, and at 2 in the afternoon. The mean for the whole year is obtained by adding all the obſervations together, and dividing the ſum by the number of obſervations.

* De Prony's Architecture Hydraulique, p. 298.

† The conſtruction of the veſſel fit for this purpoſe, as alſo the manner of exhauſting it, will be deſcribed hereafter.

the time of weighing the air. And this precaution has been obſerved in the table of ſpecific gravities. See p. 95.

The knowledge of the preſſure of the atmoſphere, and of the perpendicular pillar of quickſilver, which is equivalent to it, enables us to calculate the actual preſſure of the atmoſphere upon the whole globe of the earth, upon the human body, or upon any other body; and it appears that this preſſure is prodigiouſly great, yet we do not find it incommodious or oppreſſive, becauſe we are preſſed on every ſide by it, and the preſſure on the ſurface of our bodies is counteracted by the fluids and ſolids of our bodies, which are almoſt entirely non elaſtic. If that preſſure be removed from one ſide, then it will be found to act with prodigious force on the other ſide.

As the preſſure of the atmoſphere ſupports a perpendicular pillar of quickſilver between 28 and 31 inches high, the weight of ſuch a pillar, let its baſe be what it may, ſhews the preſſure of the atmoſphere upon a ſurface equal to that baſe. Now a pillar of quickſilver, whoſe baſe is an inch ſquare, and whoſe altitude is 28 or 31 inches long, weighs 13,75, or 15,23 pounds avoirdupoiſe, the mean of which is 14,49 pounds; therefore at a mean the preſſure of the atmoſphere upon every ſquare inch, at the ſurface of the earth, is about 14 $\frac{1}{2}$ pounds avoirdupoiſe; then by the rule of proportion, or ſimply by multiplication, we may eaſily find out the preſſure upon any given ſurface. Thus the preſſure of the atmoſpher atmoſphere on a ſquare foot, (which contains 144 ſquare inches) is equal to 144 times 14½ pounds, viz. to 2088 pounds. The preſſure of the atmoſphere on the body of a middle ſized human being (reckoning its ſurface equal to 12 ſquare feet) is 12 times 2088; that is 25056 pounds, or upwards of eleven tons. The preſſure on the ſurface of the whole earth (which, in round numbers, is equal to 5575680000000000 ſquare feet,) is equal to about 11642019840000000000 pounds.

It is now neceſſary to examine the elaſtic property of air.

If from a veſſel full of water, part of the water be removed, then the cavity of that veſſel will not be entirely occupied by water. Now the ſame thing cannot be done with air; for if from a veſſel full of air, half the air be removed by means of a proper engine, and the entrance of other air be prevented, the veſſel will ſtill remain entirely full of air, only the air in it will be half as denſe as it was before. If, inſtead of the half, you remove a much greater portion of the air from the abovementioned veſſel, the veſſel will ſtill remain entirely full of air; only the air in it will be proportionately leſs denſe. In ſhort, by removing the preſſure, a quantity of air may always be expanded; nor is it known to what degree this expanſion will reach; conſequently it is not in our power to determine the extent of the atmoſphere.

On the other hand, by increaſing the preſſure proportionately,

portionately, a quantity of air may be condenſed into any given ſpace, however ſmall; the denſity of the compreſſed air increaſing according as the bulk is diminiſhed. Nor has this condenſation any known limits, though it ſeems rational to ſuppoſe that a limit it muſt undoubtedly have.

If a glaſs veſſel full of air be immerſed in water with its aperture downwards, the water immediately under it, which at firſt lies even with its aperture, will gradually riſe in the veſſel in proportion as the veſſel is conveyed deeper and deeper into the water; the air in it being compreſſed and condenſed by the perpendicular altitude of the ſuperincumbent water. On drawing the veſſel upwards, the air in it will expand again.

This experiment ſhews that air is compreſſible; but the following experiment will ſhew that the bulk of a given quantity of air is inverſely (and of courſe its denſity is directly) as the compreſſing force; for inſtance, if a certain weight compreſſes a quantity of air into the half of its original bulk, twice that weight will compreſs it into a quarter of its original bulk; ten times that weight will force it into the 20th part of its original bulk; and ſo on.

Take a cylindrical glaſs tube bent in the form of ABCD, fig. 4. Plate XIII. open at A, and cloſed at D, and place it with the bent part downwards; pour as much quickſilver into the aperture A, as will barely fill the horizontal part BC, which will confine the air in DC. This air, like the air which is about the apparatus, &c. is compreſſed by the uſual preſſure of the atmoſphere, and this preſſure is repreſented by (ſince it is equivalent to) the actual altitude of the mercury in the barometer. Now, if you pour more quickſilver into the aperture A, the air in C D will thereby be compreſſed into a narrower ſpace; as is indicated by the mercury riſing into the part C D, and it will be found, that the ſpace D *e*, in which the air has been contracted by the preſſure of the perpendicular pillar of mercury *g f*, (the altitude of which muſt always be reckoned from the level of the ſurface *e g* of the mercury in the part C D) in addition to the uſual preſſure of the atmoſphere, is to its original bulk C D, as the uſual preſſure of the atmoſphere (or as the actual altitude of the barometer) is to the ſum of that actual altitude, and the altitude *g f*. Thus when *g f* is equal to the actual altitude of the mercury in the barometer, then the preſſure on the confined air is twice as great as if it were preſſed by the atmoſphere only; therefore that air will be confined into the half of its original bulk, viz. D *e* will be the half of D C. When the altitude *g f* is made equal to twice the altitude of the mercury in the barometer, then the preſſure on the confined air will be three times as great as if it were preſſed by the atmoſphere only; hence D *e* will be found equal to a third part of D C; and ſo on.

The expanſion of air in proportion to the diminution of the preſſure, may be ſhewn by a variety of experiments.

experiments. We ſhall for the preſent, however, deſcribe only one which may be eaſily performed.

Take a cylindrical glaſs tube, cloſed at one end and open at the other, fill it with quickſilver to a certain height, and leave the reſt full of air (or, as it would commonly be expreſſed, leave it empty); put a finger upon the aperture of the tube; turn the tube with the aperture downwards; immerge that aperture together with the finger, in a baſon of quickſilver, then remove the finger; and it will be found that the air which was left into the tube, and which now occupies the upper, that is the cloſed, part of the tube, has enlarged its dimenſions. Suppoſe, for inſtance, that the tube be 30 inches long, that it be filled with mercury, excepting 8 inches. When the tube is inverted, as in fig. 5. Plate XIII. the air will occupy the upper part A B, and the mercury the lower part B C; but the part A B, which is occupied by the air, will be found to be longer than 8 inches; the reaſon of which is, that the original quantity, viz. 8 inches of air, which before the tube was inverted, was preſſed by the atmoſphere, now ſuſtains a lower degree of preſſure; that is, the preſſure of the atmoſphere is partly counteracted by the pillar of mercury B C. Therefore, ſince the bulks of the ſame quantity of air are inverſely as the preſſures, it will always be found that the difference of the actual altitude of the mercury in the barometer, and the altitude B C of the mercury in the above-mentioned tube, is to the

the actual altitude of the mercury in the barometer, as 8 inches (viz. the original bulk of the confined air) is to its preſent bulk AB; ſo that if the actual altitude of the mercury in the barometer be 28 inches, CB will be found equal to 14 inches, and AB equal to 16 inches; for in that caſe 28—14 (viz. 14) : 28 : : 8 : 16.

Air has been left for ſeveral years very much compreſſed in proper veſſels, wherein there was nothing that could have a chemical action upon it; and afterwards on removing the unuſual preſſure, and replacing it in the ſame temperature, the air has been found to recover its original bulk, which ſhews that the continuance of the preſſure had not diminiſhed the elaſticity of it in the leaſt perceptible degree.

CHAPTER IX.

OF THE DENSITY AND ALTITUDE OF THE ATMOSPHERE, TOGETHER WITH THE METHOD OF MEASURING ALTITUDES BY MEANS OF BAROMETRICAL OBSERVATIONS.

EXPERIENCE ſhews that the atmoſphere, or the air, which ſurrounds the earth, is of different denſities at different diſtances from the centre thereof. Our direct experiments, however, do not reach to any great heights into the regions of the atmoſphere. But the numerous experiments, which have been made on the compreſſion of air, the moſt convincing of which have already been mentioned, prove that air is condenſed in proportion to the force which compreſſes it, or that it expands in the inverſe ratio of that force, and that it does not loſe any portion of its elaſticity by remaining long confined. We are, therefore, authoriſed to ſuppoſe that the air, at all diſtances from the earth, is more or leſs denſe, according as it is ſituated nearer to, or farther from, it; or according as it is preſſed by a greater or leſſer weight of ſuperincumbent air. We may alſo conclude, that, not knowing how far air may be expanded, we cannot determine to what height the atmoſphere is extended.

But

But the compreſſion ariſing from the weight of the ſuperincumbent air, though by far the principal, is not the only cauſe upon which the various denſity of the atmoſphere depends. In ſhort, all the cauſes, which ſeem to concur towards the production of that effect, are, 1. The various quantity of ſuperincumbent air at different altitudes; 2. The decreaſing attraction of the earth, or the decreaſing weight of bodies, in proportion to the ſquares of the diſtances from the centre of the earth; 3. The influence of heat and cold; 4. The admixture of vapours and other fluids; and, 5. The attraction of the moon and other celeſtial bodies.

For the ſake of perſpicuity, we ſhall examine each of thoſe cauſes ſucceſſively, and in the firſt place we ſhall endeavour to explain the effects of preſſure.

Imagine that A B C D, fig. 6, Plate XIII. is a pillar, or veſſel, full of air, reaching from the ſurface A B of the earth, to the fartheſt part C D of the atmoſphere; for whatever is proved with reſpect to the denſity of the air in this pillar, or portion of the atmoſphere, will evidently ſtand good with reſpect to any other contiguous pillar or portion of it, and, of courſe, with reſpect to the whole atmoſphere.

Imagine likewiſe, that this pillar is divided by partitions parallel to the horizon, into a vaſt number of equal ſpaces, A B *e f*, *e f g h*, *g h i k*, *i k m n*, &c.

Now as the denſity of the air is continually decreaſing from the earth upwards; therefore, ſtrictly ſpeaking, that denſity muſt be various, even in different parts of every one of thoſe ſpaces: yet as thoſe ſpaces may be conceived to be infinitely ſmall, we may, without any ſenſible error, ſuppoſe that the denſity of the air is uniform throughout the various parts of any one of them.

Since the denſity of the air is always as the force which compreſſes it; and ſince the air in every part of the atmoſphere is preſſed by the weight of the ſuperincumbent air; it follows that the denſity of the air in AB*ef*, is to the denſity of the air in *efgh*, as *ef*CD is to *gh*CD. So that the difference between the preſſures on *ef* and on *gh* (or between the quantities of air AB*ef*, and *efgh*,) is equal to the quantity of air *efgh*. For the ſame reaſon, the difference between the preſſures on *gh* and on *ik* (or between the quantities of air in *efgh* and *ghik*) is equal to the quantity of air *ghik*. Alſo the difference between the preſſures on *ik* and on *mn* (or between the quantities of air *ghik* and *ikmn*) is equal to the quantity of air *ikmn*; and ſo on. Therefore the quantities of air, or the denſities of air, in thoſe ſpaces, are proportional to the quantities of which they themſelves are the differences. But when there is a ſeries of quantities, whoſe terms are proportional to their own differences, then both thoſe quantities and their differences,

differences, are in geometrical progreſſion [*]; therefore the denſities, or quantities, of air in the equal ſpaces AB*ef*, *efgh*, *ghik*, *ikmn*, &c. are in geometrical progreſſion.

It muſt likewiſe be obſerved, that the heights of thoſe equal ſpaces above the ſurſace AB of the earth, are in arithmetical progreſſion; viz. if the ſecond ſpace be one inch above the ſurface, the next will be two inches above that ſurface, the next to that will be three inches, and ſo on; or inſtead of inches their altitudes may be of any other dimenſion, as the one-hundredth, or the one-thouſandth part of an inch. From all which we derive a very remarkable concluſion; namely, *that if the altitudes above the ſurface of the earth be taken in arithmetical progreſſion, the denſities of the air at thoſe altitudes will be in geometrical progreſſion decreaſing.*

Thus, for inſtance, if at a certain altitude the air be half as denſe as it is immediately on the ſurface of the earth; then at twice that altitude, the air will be four times leſs denſe than upon the ſurface of the earth; at three times that altitude, it will be eight times leſs denſe; and ſo forth.

Experience, aſſiſted by calculation, ſhews that at the diſtance of ſeven miles from the ſurface of the earth, the air is about four times leſs denſe than it is

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[*] Let A, B, C, D, &c. be a ſeries of quantities, and if thoſe quantities be proportional to their own differences, we have $A : A - B :: B : B - C :: C : C - D$, &c. hence converſely (Eucl. Cor. to Prop. 19. B. v.) $A : B :: B : C :: C : D$, &c.

cloſe to that ſurface *. Now the knowledge of this fact will enable us to conſtruct a table of denſities (or of preſſures) of the atmoſphere at all altitudes from the ſurface of the earth; which may be done in the following manner:

Take the altitudes in arithmetical progreſſion, viz. 7 miles, 14, 21, 28, 35, &c. Then for the denſities, ſay, by the rule of three, as 1 is to $\frac{1}{4}$, ſo is $\frac{1}{4}$ to a fourth proportional, which is $\frac{1}{16}$, and ſhews, that at the height of 14 miles the denſity of the atmoſphere is the 16th part of what it is cloſe to the ſurface of the earth. Again, ſay, as $\frac{1}{4}$ is to $\frac{1}{16}$, ſo is $\frac{1}{16}$ to a fourth proportional, which is $\frac{1}{64}$, and ſhews, that at the diſtance of 21 miles the denſity of the atmoſphere is the 64th part of what it is cloſe to the ſurface, &c. Thus you have the denſities (or the preſſures which are as the denſities) of the atmoſphere at the undermentioned diſtances.

Altitudes in miles.			Correſpondent denſities.
0	—	—	1
7	—	—	$\frac{1}{4}$
14	—	—	$\frac{1}{16}$
21	—	—	$\frac{1}{64}$
28	—	—	$\frac{1}{256}$
35	—	—	$\frac{1}{1024}$
42	—	—	$\frac{1}{4096}$
49	—	—	$\frac{1}{16384}$
56	—	—	$\frac{1}{65536}$
&c.			&c.

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* Cotes's Hyd. Lectures, Lect. IX.

Then,

Then, in order to find the denſities correſpondent to the intermediate altitudes, take an arithmetical mean proportional between 7 miles and 14 miles, which is 10 $\frac{1}{2}$ miles *; alſo, take a geometrical mean proportional between the denſities of the air at 7, and at 14 miles, viz. between $\frac{1}{4}$ and $\frac{1}{16}$, which is $\frac{1}{8}$ †; and this is the denſity of the air at the altitude of 10 $\frac{1}{2}$ miles. Again, take an arithmetical mean proportional between 14 and 21 miles, which is 17$\frac{1}{2}$ miles; alſo, take a geometrical mean proportional between the denſities of the air at the abovementioned two altitudes, viz. between $\frac{1}{16}$ and $\frac{1}{64}$, which is $\frac{1}{32}$, and it expreſſes the denſity of the air at the height of 17 $\frac{1}{2}$ miles. After the ſame manner you may take an arithmetical mean proportional between 17 $\frac{1}{2}$ and 21 miles, and a geometrical mean proportional between the denſities at thoſe altitudes. In ſhort, the like operation may be performed with any two altitudes, and their correſpondent denſities; by which means a table of denſities,

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* An arithmetical mean proportional between two numbers is found by taking the half of the ſum of the two numbers. Thus the ſum of 7 and 14 is 21, the half of which is 10 $\frac{1}{2}$.

† A geometrical mean proportional between two numbers, is found by extracting the ſquare-root of the product of the two numbers. Thus $\frac{1}{4}$ multiplied by $\frac{1}{16}$, gives $\frac{1}{64}$, the ſquare root of which is $\frac{1}{8}$; and $\frac{1}{8}$ is the geometrical mean between $\frac{1}{4}$ and $\frac{1}{16}$.

anſwering to certain altitudes, may be conſtructed. This laborious operation, however, may be avoided; for the ſame thing may be obtained by uſing a table of logarithms, which logarithms in fact are a ſet of numbers in arithmetical progreſſion, annexed to another ſet of numbers, which are in geometrical progreſſion; ſo that the former may repreſent the altitudes, whilſt the latter repreſent the denſities of the atmoſphere correſpondent with thoſe altitudes.

The principal uſe of ſuch a table is for meaſuring perpendicular altitudes above the ſurface of the earth, by means of barometrical obſervations, the principle of which operation we ſhall endeavour to explain.

The barometer, as has been ſhewn in the preceding chapter, ſhews the actual preſſure of the atmoſphere, or the denſity of the air at the place where it is ſituated; therefore the altitude of the mercury in a barometer, placed at the top of a mountain, will not be ſo great as the altitude of the mercury in a barometer placed on the ſea ſhore. Now thoſe altitudes of the mercury being as the denſities, and the denſity at the ſurface of the earth, or on the ſea ſhore, being called one in the table, we ſay, as the barometrical altitude at the ſurface is to the barometrical altitude on the mountain, ſo is one to the denſity of the air at the top of the mountain; and finding the denſity thus obtained in the table, we have againſt it the correſpondent altitude, or the

the perpendicular diſtance between the ſituations of the two barometers.

So far the operation would be eaſy and uſeful, provided its reſults were attended with ſufficient accuracy; but the other above-mentioned cauſes, which affect the denſity of the atmoſphere, render a variety of corrections neceſſary for the attainment of a uſeful degree of accuracy in ſuch meaſurements. The difficulty of inveſtigating the peculiar effects of thoſe cauſes, as alſo of compenſating for their effects, involve the operation in a good deal of difficulty, on which account we ſhall give a full examination of this ſubject in the note (1.); and ſhall

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(1.) The mechanical properties of the atmoſphere are analogous to the properties of a particular ſpecies of curve lines, called *logarithmic curves*; hence the knowledge of the properties of the latter is of conſiderable aſſiſtance in elucidating the properties of the former. But the nature of logarithmic curves is probably not ſufficiently underſtood by the greateſt number of my readers: I ſhall, therefore, briefly ſubjoin ſuch of their properties as may ſuffice to illuſtrate the doctrine of the atmoſphere.

Of the Logarithmic Curves.

Definitions. Upon an indefinite right-line AE, fig. 7, Plate XIII. make the intervals AB, BC, CD, &c. equal to one another; or (which is the ſame thing) make the diſtances AB, AC, AD, &c. in arithmetical progreſſion. From the points A, B, C, D, E, &c. draw the lines AF, BG, CH, DI, &c,

ſhall here proceed to give a ſhort idea of the influence of the above-mentioned cauſes on the denſities of the atmoſphere, at different altitudes and different times.

&c. parallel to each other, and in geometrical progreſſion; viz. making A F to B G, as BG to CH, as CH to DI; and ſo on. Then a curve line F G H I K, drawn through the extremities of thoſe parallel lines, is called a *logarithmic curve*. The indefinite right-line A E is its *axis*, which will be ſhewn to be an *aſymptote* to the curve, viz. it will never meet the curve; and the lines AF, BG, CH, DI, &c. are the *ordinates*.

Since the ordinates may be taken in any geometrical proportion, it is evident that there is an infinite variety of logarithmic curves.

Propoſition I. *The axis* A E *is an aſymptote to the logarithmic curve.*

Since the ordinates are in geometrical progreſſion, HC is ſuch a part of DI, as BG is of H C, as A F is of B G, as the next ordinate is of AF, and ſo on without end; therefore no ordinate can ever be equal to 0; for that 0 would be no part of the preceding ordinate; hence the axis and the curve can never meet; though when produced towards the ſhorter ordinates, they come continually nearer to each other.

Prop. II. *If a tangent and an ordinate be drawn from any point in a logarithmic curve; the ſubtangent, or part of the axis, which is contained between the interſections of the ordinate and the tangent, is a conſtant or invariable quantity.*

Take E and F, any two points in the curve, fig. 8, In the preceding inveſtigation of the decreaſing denſity of the atmoſphere, the force of gravity has been ſuppoſed to act uniformly; whereas, in truth, that force decreaſes according as the ſquares of the

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Plate XIII. indefinitely near to each other, and through each of them draw a tangent and an ordinate to the curve; TE, VF, being the tangents, and BE, CF, the ordinates. Draw another ordinate D G, as diſtant from CF as CF is from BE, and through E and F draw E *n*, F *r*, both parallel to the axis.

Since the diſtances B C, C D, are equal, we have, from the definition of the curve, D G : F C : : F C : B E; by diviſion, D G — F C : F C : : F C — B E : B E : : G *r* : F C : : F *n* : B E.

It is evident from the paralleliſm of the lines F *r*, E *n*, T D; as alſo of the lines D G, C F, B E, that the triangles F G *r*, F V C, are ſimilar, and ſo likewiſe are the triangles F E *n*, E T B; hence G *r* : F C : : F *r* : V C; alſo F *n* : E B : : E *n* : B T : : G *r* : F C : : F *r* : V C. But E *n* is equal to F *r*; therefore the ſubtangent B T muſt be equal to the ſubtangent C V.

By the ſame mode of reaſoning it may be proved that B T is equal to any other ſubtangent of the ſame curve; or that the ſubtangent is an invariable quantity.

Cor. Logarithmic curves, that have equal ſubtangents, are equal.

Prop. III. *If four ordinates to a logarithmic curve be in the ſame ratio, viz. the firſt be to the ſecond as the third to the fourth; and if through the extremities of the firſt and third a ſecant be drawn, and another ſecant be drawn through the extremities of the ſecond and fourth; then the part of the axis which* the diſtances from the centre of the earth increaſe (p. 61. Part I.); ſo that the particles of air which are at a diſtance from the earth gravitate leſs than thoſe which are nearer to it; hence, on this account, the denſity

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which is contained between the interſections of the firſt ſecant and the firſt ordinate, will be equal to that part of the ſame axis which is contained between the interſections of the ſecond ſecant and the ſecond ordinate.

Thus, in fig. 9, Plate XIII. if AF : DI : : BG : EK, in which caſe, from the nature of the curve, AD=BE, and AB=DE; and if the ſecants GFT, KIV, be drawn; then TA will be equal to VD.

Through F and I draw FS, and IL, parallel to the axis. Then ſince AF : DI : : BG : EK, we have by alternation AF : BG : : DI : EK; inverſely, BG : AF : : EK : DI; and, by diviſion, BG—AF (=GS) : AF : : EK—DI (=LK) : DI; inverſely, AF : GS : : DI : LK. But the triangles DIV, LKI, are ſimilar, and ſo likewiſe are the triangles AFT, FGS; therefore TA : FS : : AF : GS : : (from the above analogy) DI : LK : : VD : IL. Then ſince in the analogy TA : FS : : VD : IL, the ſecond and fourth terms are equal, viz. FS=IL, or AB=DE; the other two terms muſt likewiſe be equal, viz. TA=VD.

Prop. IV. *The ſpace, which is circumſcribed by any two ordinates, and ſuch parts of the curve and of the axis as lie between thoſe ordinates, is equal to the rectangle of the ſubtangent and the difference of the ordinates.*

Thus, fig. 10, Plate XIII. the ſpace GBEL is equal to TE × SL; TL being the tangent at the point L.

Imagine

denſity of the atmoſphere at a given altitude muſt be leſs than if the force of gravity acted uniformly. Yet, ſince the altitudes of the higheſt mountains make a trifling addition to the radius of the earth, the

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Imagine D I to be drawn infinitely near and parallel to E L; and I r to be drawn through the interſection I, parallel to the axis.

From the ſimilarity of the triangles L I r, L T E, we have $EL : ET :: Lr : Ir$; hence $ET \times Lr = EL \times Ir =$ the area D E I r = (ſince, when I D is infinitely near to E L, the triangle L I r vaniſhes) D E L I. And the ſame thing may be ſaid of any other point very near I, and of another next to that, &c. Therefore (the ſubtangent E T being an invariable quantity) the ſum of all the ſmall ſpaces, ſuch as D E L I, between L E and B G; or the ſpace B E L G, is equal to $ET \times LS$ (L S being the ſum of all the differences L r).

Corollary 1. The whole area, which is contained between any ordinate L E, the curve, the axis, and infinitely extended towards F A, is equal to the rectangle of that ordinate and the ſubtangent, viz. to $LE \times TE$; ſince when the area is infinitely extended towards A F, the laſt ordinate vaniſhes, viz. EL becomes equal to the difference of EL and the laſt ordinate.

Cor. 2. The ſpaces, which begin at different ordinates, and are thus infinitely extended, are as the ordinates from which they begin to be reckoned.

Cor. 3. The ſpace which lies between any two ordinates, is to the ſpace which lies between any other two ordinates, as the difference of the firſt two ordinates is to the difference of the two others.

Prop

the diminution of the gravitating force will have no ſenſible influence in our meaſurements of altitudes by means of the barometer. Thoſe perſons, however, who wiſh not to neglect that circumſtance,

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Prop. V. *The diſtances, or parts of the axis, which lie between two equal ordinates in two, or more, different logarithmic curves, are as the ſubtangents of thoſe curves reſpectively.*

Thus, if in the two logarithmic curves, FIG, QKS, FA be equal to PQ, and BG be equal to HS; then it will be $AB : TB :: PH : VH$; TG and VS being the tangents.

Draw two ordinates indefinitely near to GB and HS, and draw In, Kr, parallel to the axes; then ſince AF, LI, BG, are reſpectively equal to PQ, NK, HS, it will be (from the definition of the curve) $AB : LB$ (or In) $::$ $PH : NH$ (or Kr); and alternately $AB : PH :: In : Kr$.

From the ſimilarity of the triangles BGT, G In, and HSV, SKr, we have $BT : In :: BG : nG :: HS : rS :: HV : rK$; whence alternately $BT : HV :: In : Kr :: AB : PH$; and inverſely, $AB : BT :: PH : HV$.

Scholium. A table of logarithms is nothing more than a ſeries of numbers in arithmetical progreſſion, annexed to another ſeries of numbers that are in geometrical progreſſion. Therefore, if the lengths of the abſciſſas AB, AC, AD, &c. of a logarithmic curve, fig. 7, Plate XIII. and the lengths of the correſponding ordinates AF, BG, CH, &c. be expreſſed in numbers; the former will be the logarithms of the latter.

either in ſuch meaſurements, or in the inveſtigation of other properties of the atmoſphere, will find the neceſſary explanations in the note below.

Heat increaſes, and, on the contrary, cold, or a diminution

Since the ratio of the ordinates as well as the lengths of the abſciſſas may be various; it follows that different logarithmic curves will repreſent different ſyſtems of logarithms.

In the curve which expreſſes the common table of logarithms, called *Briggs's logarithms*, the lengths of the ordinates are, 1 : 10 : 100 : 1000, &c. or their ratio is 10, whilſt the abſciſſas, or the logarithms, are 1, 2, 3, 4, &c.; and the ſubtangent (otherwiſe called the *module of that ſyſtem of logarithms*) is equal to 0,43429448.

It is evident that every ordinate is a geometrical mean proportional between any two other ordinates equidiſtant from it; whilſt its correſpondent abſciſſa is an arithmetical mean proportional between the abſciſſas to the other two ordinates. Thus C H, in fig. 7, is a geometrical mean between B G, and D I; and A C is an arithmetical mean between A B and A D. Hence, for inſtance, if we divide A B in two equal parts in *s*, and find a mean geometrically proportional between A F and B G, that mean will be the length of the ordinate *s o*; and A *s* is its logarithm.—Thus we may find as many ordinates and their logarithms as we pleaſe.

It follows from Prop. V. that in different ſyſtems of logarithms, the diſtances between equal ordinates, or the logarithms of equal numbers, are proportional to the ſubtangents, or modules, of their reſpective ſyſtems. Thus, if diminution of heat, contracts, the bulk of air. But this expanſion and contraction are not regular, viz. they are not exactly proportional to the degrees of heat. Beſides this, the rate of expanſion, by the ſame degrees of heat, differs according as the air is more or leſs denſe; alſo according as it is more or leſs

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if in one ſyſtem the module be M, and the logarithm of a given number be L; whilſt in another ſyſtem the module be m, and the logarithm of the ſame number be l; then it will be $M : L :: m : l$; hence $Ml = Lm$; viz. the product of the logarithm of a given number in one ſyſtem, multiplied by the module of another ſyſtem, is equal to the product of the logarithm of the ſame number in that other ſyſtem, multiplied by the module of the firſt ſyſtem.

If the module of one ſyſtem be repreſented by unity: then $1 : L :: m : l$; in which caſe $Lm = l$.

Of the ATMOSPHERE.

Thus much will ſuffice with reſpect to the properties of the logarithmic curves; we muſt now proceed to explain by means of thoſe properties, the conſtitution of the atmoſphere, and the method of determining altitudes from barometrical obſervations.

It has been already ſhewn, that the denſities of the air at different diſtances from the earth are in geometrical progreſſion decreaſing, whilſt the altitudes are in an increaſing arithmetical progreſſion; it is therefore evident, that if on a ſtraight line A M, fig. 12, Plate XIII. the diſtances A B, A C, A D, &c. repreſent the altitudes, and the ſtraight lines A O, B F, C H, D I, &c. drawn perpendicular to A M, repreſent leſs charged with moiſture. — The late General Roy, F.R.S. made a great variety of accurate experiments relative to this expanſion of air; but the reſults of his experiments will be ſtated in another part of theſe elements.

The

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repreſent, or be made proportional to, the denſities of the atmoſphere at thoſe altitudes; then a curve line O I N, drawn along the ends O, H, I, &c. of thoſe lines, will be a logarithmic curve, and may be called the *atmoſpherical logarithmic*; A M being its axis, and A O, B F, C H, &c. its ordinates. The area which lies between the firſt ordinate A O, the curve, and the axis, and is infinitely extended towards M N, may be conſidered as being equal to an infinite number of ordinates, ſituated extremely near to each other; but thoſe ordinates repreſent the quantities of air at their reſpective ſituations; therefore the abovementioned area will repreſent the whole quantity of air in the atmoſphere. Alſo the area, or part of the abovementioned area, from any one of thoſe ordinates upwards, will repreſent the whole quantity of atmoſpheric air, which exiſts beyond that altitude.

This however would be the caſe if the force of gravity acted uniformly at all diſtances from the earth, which is not true. Therefore we muſt now examine the real diminution of denſity in the atmoſphere on the true hypotheſis, viz. of the gravity's decreaſing according as the ſquares of the diſtances increaſe; in conſequence of which the denſity of the air at any given altitude muſt be greater than it would be if the force of gravity acted uniformly, in order that a given degree of preſſure may be produced upon the ſurface of the earth.

The influence of the ſun, and principally of the moon, upon the waters of the ocean, is too evident to need any particular examination. And it is evident from the laws of univerſal attraction, that thoſe celeſtial

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Let PAZ, fig. 13. Plate XIII. repreſent the circumference of the earth, S its centre, m SM an indefinite right line paſſing through the centre S, and interſecting the circumference at A. Let the altitudes SA, SB, SC, SD, differ indefinitely little from each other; but let them be in harmonical progreſſion. Alſo let the ordinates AO, BF, CG, DH, be proportional to the denſities of the atmoſphere at A, the ſurface of the earth, and at the altitudes B, C, D; but upon the ſuppoſition that the force of gravity acts uniformly. Then the curve OFGHN, drawn along the extremities of thoſe ordinates, &c. is (from what has been ſaid above) a logarithmic curve.

Now take S b, a third proportional to SB and SA; take S c a third proportional to SC and SA; alſo take S d a third proportional to SD and SA; viz. let it be

$$SB : SA :: SA : Sb$$
$$SC : SA :: SA : Sc$$
$$SD : SA :: SA : Sd$$

Then SA, S b, S c, S d, being the reciprocals of SA, SB, SC, SD; (for they decreaſe according as SA, SB, SC, SD, increaſe) muſt be in arithmetical progreſſion; it being well known that the reciprocals of quantities that are harmonically proportional, are in arithmetical progreſſion. See Malcolm's Arithmetic, B. IV. chap. 6.

Through the points A, b, c, d, draw AO, bf, cg, dh, perpendicular to the axis Am, and make them proportional to celeſtial bodies muſt act upon the atmoſphere in a ſimilar manner; that is, they muſt occaſion a flux and reflux of the atmoſphere, as well as of the ocean. But the atmoſpherical air being a fluid much

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to the *real* denſities of the air at A, B, C, D, reſpectively. Through the points O, *f*, *g*, *h*, &c. draw the curve O*fg h*, &c. which will preſently be ſhewn to be a logarithmic curve.

From the abovementioned analogies, we have $SD \times Sd = \overline{SA}|^2 = SC \times Sc$; hence $Sc : Sd :: SD : SC$. Converſely $Sc : Sc - Sd\ (= cd) :: SD : SD - SC\ (= CD;)$ viz. $cd : CD :: Sc : SD$. Or, becauſe CD is indefinitely ſmall, S C will be ultimately equal to S D: hence, by ſubſtitution, the laſt mentioned analogy becomes $cd : CD :: Sc : SC :: Sc \times SC : SC \times SC :: \overline{SA}|^2 : \overline{SC}|^2$. Therefore $cd = DC \times \frac{\overline{SA}|^2}{\overline{SC}|^2}$; and by equal multiplication, it will be $cd \times cg = CD \times cg \times \frac{\overline{SA}|^2}{\overline{SC}|^2}$.

Now C D expreſſes the bulk of the ſtratum C D G H (for as CD is very ſmall, the air may, without any ſenſible error, be ſuppoſed to be uniformly denſe throughout the ſtratum C D G H); *cg*, by conſtruction, expreſſes the real denſity of the ſame ſtratum, and $\frac{\overline{SA}|^2}{\overline{SC}|^2}$ expreſſes the gravitation of each particle; for ſince the force of gravity is inverſely as the ſquares of the diſtances, if the gravity at the ſurface A be called unity, we have $\overline{SC}|^2 : \overline{SA}|^2 :: 1 : \frac{\overline{SA}|^2}{\overline{SC}|^2}$ = the gravity at C.

much more variable than water, the action of the ſun and moon upon it becomes much leſs apparent to us, ſince they muſt frequently concur with, or be counteracted by, the much more powerful effects

of

But the weight, or preſſure, of any ſtratum is as its bulk, as its denſity, and as its gravity conjointly; therefore CD $\times$ *cg* $\times \frac{\overline{SA}^2}{\overline{SC}^2}$, or its equal *cd* $\times$ *cg*, expreſſes the preſſure of the ſtratum CDGH. And the ſame reaſoning may be adapted to any other ſucceeding ſtratum. But the ſum of all ſuch ſtrata as *cdhg* (or *cd* $\times$ *cg*) from *cg* downwards, forms the area *cmng* below *cg*; therefore the whole preſſure upon C, ariſing from the gravitation, or preſſure, of all the air above it, is as the area *cmng*. But the denſity *cg* of the air is as the preſſure; therefore any area as *cmng* below any ordinate, as *cg*, is proportional to that ordinate. Now this is a characteriſtic property of the logarithmic curves; therefore it ſhews that the curve O*fghn* is a logarithmic curve. See Cor. 2. to Prop. IV. in page 237.

Farther it appears, that this curve is exactly equal to the curve OFGHN; for if B come continually near to A, and ultimately coincide with it, the ultimate ratio of AB to A*b*, and of BF to *bf*, muſt be that of equality. Then the tangents OFK, O*fk*, form equal angles with the ordinate AO; conſequently the ſubtangents AK, A*k*, are equal, and the curves OFGHN, O*fghn*, are alſo equal. See Cor. to Prop. II. in page 235.

The diſtances S*b*, S*c*, S*d*, are in arithmetical progreſſion, and ſo are the diſtances A*b*, A*c*, A*d*, becauſe the latter are reſpectively equal to SA — S*b*, SA — S*c*, SA — S*d*.

of heat and cold, of dryneſs and moiſture, of winds, &c. (See the Abbé Mann's Diſſert. on the Flux and Reflux of the Atmoſphere, in the fourth vol. of the Tranſ. of the Ac. of Sc. at Bruſſels, or in the Phil.

Sd. Then ſince $Ofghn$ is a logarithmic curve, and the abſciſſæ Ab, Ac, Ad, are in arithmetical progreſſion; the ordinates bf, cg, dh, muſt be in geometrical progreſſion. But theſe ordinates repreſent the real denſities of the air at B, C, D; therefore the denſities of the air at B, C, D, are in geometrical progreſſion, on the true hypotheſis of the decreaſe of gravity in proportion to the ſquares of the diſtances from the centre of the earth.

Upon the whole then it appears that the difference between the two hypotheſes, viz. of an uniform, and of a decreaſing gravity, is, that the ordinates bf, cg, dh, &c. which repreſent the denſities of the air at the places B, C, D, reſpectively, are a little longer than the correſponding ordinates BF, CG, DH. And they are longer, becauſe the abſciſſas Ab, Ac, Ad, are ſhorter than the correſponding abſciſſas AB, AC, AD; recollecting that the curves OFGN, and $Ofgn$, have been demonſtrated to be equal. So that if the denſity of the air, or the preſſure of the atmoſphere, at a certain point, for inſtance, D, is to be calculated on the ſuppoſition of an uniform gravity, we muſt determine the value of the ordinate DH; but upon the true theory of a decreaſing gravity, we muſt determine the value of the ordinate dh.—The method of calculating thoſe ordinates is as follows.

The logarithmic area AONM is equal to the rectangle AO × AK (Prop. IV. in page 236, and its Corollaries) the

Phil. Magazine, vol. V.) Hence the action of the ſun, and principally of the moon, upon the atmoſphere, has been long ſurmiſed; but it is only of late years that it has been in ſome meaſure obſerved,

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area B F N M is equal to BF × AK; the area C G N M is equal to C G × A K, &c. Therefore the preſſure at the ſurface, which is proportionate to the area AONM, is equal to AO × AK. But if the air were of a uniform denſity, equal to its denſity at the ſurface A, and did not reach higher than K, its whole quantity would be expreſſed by A O × A K; therefore the whole quantity of air A O N M, gradually decreaſing in denſity, is equal to an homogeneous atmoſphere of the denſity A O, and altitude A K.

Farther, the quantity of air B F N M is to the quantity AONM, (or to A O × A K) as B F is to A O. Alſo the quantity of air C G N M, is to the quantity A O N M, (or to A O × A K) as C G is to A O; and ſo forth.

Now let fig. 14. Plate XIII. repreſent the logarithmic curve of the common table of logarithms, where the ſubtangent, or module A E, is equal to 0,43429; let AT be equal to AO, (ſee both figures) and DH to RY; then we have (by Prop. V. in page 238.) A E : A K : : A R : A D. Alſo, if V Q be equal to B F, we have AE : AK : : VR : B D.

Thoſe two analogies are of great practical uſe, viz. for finding out the preſſures or the denſities of the atmoſphere, when the altitudes are given; and, on the other hand, for finding the altitudes, or the difference between two altitudes, when the denſities at thoſe altitudes are known.

The preſſures of the atmoſphere at different heights, or the values of the ordinates A O, B F, C G, D H, &c. are obſerved, and rendered ſenſible by means of very accurate and long continued barometrical obſervations; for it may be perceived only by taking a mean of the obſervations of many years.

Toaldo

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are ſhewn by the altitudes of the mercury in the barometer, (which are the counterpoiſes to thoſe preſſures) placed at the correſponding ſituations A, B, C, D, &c. The parts AU, AR, UR, are to be found in the common table of logarithms; AE is equal to 0.43429; and AK has been aſcertained, by the following means, to be equal to 26365 feet, or five miles nearly.

When the thermometer ſtands at 32°. and the barometer ſtands at 30 inches, the ſpecific gravity of air may be reckoned equal to 0,0013066208, and the ſpecific gravity of quickſilver equal to 13,619. Therefore 0,0013066208 : 13,619 : : 1 : 10423,07 = the ſpecific gravity of quickſilver, when that of air is called one, viz. in the abovementioned circumſtances quickſilver weighs 10423,07 times as much as air: whence it follows that a perpendicular pillar of quickſilver of 30 inches in the barometer, is a counterpoiſe to a perpendicular pillar of the atmoſphere of the ſame diameter, reaching from the ſurface of the earth to the utmoſt limit M of the atmoſphere, or to a perpendicular pillar of air of an uniform denſity (viz. of the denſity at the ſurface A, ſuch as is indicated by the ordinate AO), but of 30 times 10423,07 inches, viz. of 312692,1 inches. Therefore AK, which is the ſubtangent, or the module of the atmoſpherical logarithmic, is equal to 312692,1 inches, or 26057,675 feet, or 8685,891 yards, or 4342,945 fathoms, or 5 miles, minus 342,325 feet.

The

Toaldo the learned aſtronomer of Padua, after a variety of obſervations made in the courſe of ſeveral years, found reaſon to aſſert, that *cæteris paribus*, at the time of the moon's apogeum, the mercury in the

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The practical application of the abovementioned analogies, to the method of meaſuring altitudes by means of barometrical obſervations, will be illuſtrated by one or two examples.

Example I. Suppoſe that the mercury in the barometer at A, fig. 13. viz. on the ſurface of the earth, ſtands at 30 inches, at the ſame time that the mercury of a ſimilar barometer ſituated on the top of a mountain at D, ſtands at 29,34 inches. It is required to deduce the altitude A D from thoſe obſervations.

In the firſt place it muſt be recollected, that the ſame preſſure of the atmoſphere, which cauſes a certain denſity of the air at any place A, or D, keeps up the mercury in the tube of the baromer; therefore the altitudes of the mercury in the barometers ſituated at different altitudes above the ſurface of the earth, are proportional to the denſities of the air, or to the ordinates of the atmoſpherical logarithmic at thoſe reſpective altitudes. So that in the preſent inſtance, 30 inches perpendicular altitude of mercury repreſents the ordinate AO, and 29,34 inches perpendicular altitude of mercury repreſents the ordinate D H.

Now in the logarithmic curve of the common tabular logarithms, fig. 14, Plate XIII. A T and R Y are reſpectively equal to A O and D H of the atmoſpherical logarithmic, fig. 13, Plate XIII.; therefore, taking from the common logarithmic tables, the logarithm of 30, which is the barometer riſes the 0,015 of an inch higher than at the perigeum; that at the time of the quadratures, the mercury ſtands 0,008 of an inch higher than at the time of the ſyziges; and that it ſtands

0,022

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is 1,4771213; alſo the logarithm of 29,34, which is 1,4674601; and ſubtracting the latter from the former, we obtain the remainder 0,0096612, which is equal to the portion A R of the axis.

This being obtained, we then ſay A E : A K : : A R : A D; viz. 0,4342945 : 26057,675 : : 0,0096612 : to a fourth proportional, which gives the altitude A D equal to 579,672 feet.

In finding this fourth proportional, according to the common rule of three, we may either multiply the third term by the ſecond, and then divide the product by the firſt; or we may firſt of all divide the ſecond term by the firſt, and then multiply the quotient by the third term; the reſult, as is well known, turning out always the ſame. But in this operation the ſecond method is attended with a practical advantage, which will be pointed out preſently.

Example II. Suppoſe the perpendicular pillar of mercury in the barometer at B, to be 28,65 inches, and that of the mercury in a ſimilar barometer at D, to be 26,97 inches. It is required to determine thereby the perpendicular diſtance B D, between the two ſtations, or places of obſervation.

Suppoſing the ordinates U Q, R Y, to be reſpectively equal to the above-mentioned mercurial altitudes; we take the logarithm of 28,65, which is 1,4571246, and the logarithm of 26,97, which is 1,4308809; then ſubtracting the latter

0,022 of an inch higher when the moon in each lunation comes neareſt to our zenith (meaning the zenith of Padua, where the obſervations were made) than when it goes fartheſt from it. *Journal des Sciences Utiles.*

In

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latter from the former, the remainder 0,0262437 is equal to U R.

This being obtained, we then ſay, as mentioned above, page 246, A E : A K : : V R : B D; viz. 0,4342945 : 26057,675 : : 0,0262437 : to a fourth proportional, to find which, we divide the ſecond term by the firſt, and obtain the quotient 60000; then multiply the third term by this quotient, and the product, viz. 1574,622 feet, is the diſtance BD.

Here it is to be obſerved, that the firſt and ſecond terms of the abovementioned analogy, are conſtantly the ſame, viz. 0,4342945, and 26057,675; and of courſe their quotient is likewiſe conſtantly the ſame, namely, the very convenient number 60000; therefore the operation of determining the altitudes, &c. may be rendered very ſhort; for the whole conſiſts in multiplying the difference of the logarithms of the mercurial altitudes, by 60000, and the product gives the altitude ſought, in feet. And if we want the anſwer in fathoms, the operation will be rendered ſhorter ſtill; for ſince ſix feet are equal to one fathom, 60000 feet muſt be equal to 10000 fathoms. Therefore, in that caſe, we need only multiply the difference of the logarithms by 10000; which is eaſily done by removing the comma, which ſeparates the decimal part of the logarithmic remainder, four places of figures to the right. Thus, in the laſt example, the lo-

garithmic

In the 7th vol. of the Philoſophical Magazine, there is a paper of L. Howard, Eſq. which contains ſeveral curious obſervations relative to this ſubject. This gentleman found both from his own obſervations,

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garithmic remainder is 0,0262437, which, by removing the comma four places to the right, becomes 262,437, and expreſſes the diſtance BD in fathoms; the ſame as before, 262,437 fathoms being equal 1574,622 feet.

It is now neceſſary to recollect that this rule has been eſtabliſhed upon the ſuppoſitions that the ſpecific gravity of mercury is 13,619; that the ſpecific gravity of air is 0,0013066208; that the temperature of the air, as well as of the mercury, is 32°. and that the mercurial altitude in the barometer, ſituated on the ſurface of the earth, is equal to 30 inches. But if any one of thoſe circumſtances happens to be altered, then the reſult of the operation, according to the above-mentioned rule, will deviate more or leſs from the truth. For inſtance, if the temperature happens to be higher than 32°, then the ſpecific gravities of the air, and of the mercury, will differ from the above-mentioned ſtatements, and of courſe the module of the atmoſpherical logarithmic, which is the ſecond term of the analogy, &c. muſt be altered accordingly.—The ſame thing may be ſaid with reſpect to the other particulars.

Notwithſtanding the intricacy of ſolution which ariſes from the concurrence and fluctuation of the above-mentioned circumſtances, the particular effects of each cauſe have been examined, with immenſe trouble and aſſiduity, by various ingenious philoſophers; and rules have been formed for correcting in a great meaſure the errors which obſervations, and from an examination of the Meteorological Journal of the Royal Society, which is publiſhed annually in the Phil. Tranſactions, that the moon had a manifeſt action upon the barometer.

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which ariſe therefrom. We ſhall now proceed to examine thoſe rules, and the facts upon which they are eſtabliſhed.

Since the bulks of bodies are increaſed by the acceſſion of heat, and of courſe their ſpecific gravities are thereby diminiſhed; and ſince different bodies are expanded differently by equal increments of heat; it follows that, under the ſame atmoſpherical preſſure, the mercury in the barometer muſt ſtand higher or lower, according as it is hotter or colder. Alſo the ratio of the gravity of mercury to that of air, will, *cæteris paribus*, vary with the increaſe or decreaſe of temperature; but this variation has been found to be not exactly proportional to the degrees of heat. Hence in meaſuring altitudes by the barometer, either the ſubtangent of the atmoſpherical logarithmic muſt be derived from the actual temperature of the mercury and of the air at the time of making the obſervations; or both the actual denſity of the air, and the obſerved altitude of the mercury in the barometer, muſt be reduced to what they would be if the degree of temperature were 32°.—The latter method is the moſt expeditious.

Mercury has been found to expand nearly in the exact proportion of the degrees of heat; its expanſion for every degree of heat, from 32°. upwards, or the contraction for every degree of heat from 32°. downwards is equal to 0,000102 of the whole bulk, which at 32°. is called one, or meter. “It appears, *he ſays*, to me evident, that “the atmoſphere is ſubject to a periodical change “of gravity, whereby the barometer, on a mean of “ten years, is depreſſed at leaſt one-tenth of an “inch

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or unity: ſo that if a quantity of quickſilver, which at the temperature of 32°. meaſures one cubic inch, at the temperature of 33°. meaſure 1,000102 inches; it will, at the temperature of 34°. meaſure 1,000204 inches, &c. But though quickſilver in itſelf be expanded regularly by the acceſſion of heat; yet in the tube of the barometer, the perpendicular pillar of it is not expanded with the ſame regularity; and this deviation from that regularity is owing to two cauſes, viz. to the expanſion of the glaſs tube, and to the probable generation of ſome elaſtic fluid, which being extricated from the mercury by the heat, occupies the empty part of the barometrical tube above the quickſilver.

The actual increaſe of altitude in a barometrical pillar of mercury, ariſing from an increaſe of temperature, was determined from actual experiments on the barometer itſelf, by the late very ingenious General Roy. When the barometer ſtood at 30 inches, this gentleman expoſed a barometer to different degrees of heat in a very proper apparatus, wherein the whole column could be rendered of the ſame uniform temperature; and meaſured the increaſe or decreaſe of altitude, which was occaſioned by the various degrees of heat. (See his valuable paper in the 67th vol. of the Philoſophical Tranſactions.) The reſult of his experiments is contained in the annexed table, where the firſt column expreſſes the degrees of heat, to which the barometer was expoſed; the ſecond column ſhews the altitudes of the mercurial

“ inch while the moon is paſſing from the quarters to the full and new; and elevated, in the “ ſame proportion, during the return to the quar“ ter.” A great fall of the barometer generally takes

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rial column, correſpondent with the different degrees of heat; and the third column expreſſes the differences of thoſe expanſions.

212°.	30,5117	
202.	30,4888	 0,0229
192.	30,4652	 0,0236
182.	30,4409	 0,0243
172.	30,4159	 0,0250
162.	30,3902	 0,0257
152.	30,3638	 0,0264
142.	30,3367	 0,0271
132.	30,3090	 0,0277
122.	30,2807	 0,0283
112.	30,2518	 0,0289
102.	30,2223	 0,0295
92.	30,1922	 0,0301
82.	30,1615	 0,0307
72.	30,1302	 0,0313
62.	30,0984	 0,0318
52.	30,0661	 0,0323
42.	30,0333	 0,0328
32.	30,0000	 0,0333
22.	29,9662	 0,0338
12.	29,9319	 0,0343
2.	29,8971	 0,0348
0.	29,8901	 0,0070

“ From

takes place before high tides, eſpecially at the time of new or full moon.

In the year 1794, a regular riſe and fall of the mercury in the barometer was obſerved at Calcutta by

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"From the experiments," *Col. Roy ſays*, "it appears, that a column of quickſilver, of the temperature of 32°. ſuſtained, by the weight of the atmoſphere, to the height of 30 inches in the barometer, when gradually affected by different degrees of heat, ſuffers a progreſſive expanſion; and that having acquired the heat of boiling water, it is lengthened $\frac{5117}{10000}$ parts of an inch: alſo, that the ſame column, ſuffering a condenſation by 32°. of cold, extending to the zero of Fahrenheit, is ſhortened $\frac{1092}{10000}$ parts, the weight of the atmoſphere remaining in both caſes unaltered; but that in the application of the barometer to the meaſurement of altitudes, ſince the preſſure and length of the column change with every alteration of vertical height, the correction, depending on the difference of temperature of the quickſilver, will neceſſarily augment or diminiſh by a proportionable part of the whole. Thus, if the weight of the atmoſphere ſhould at any time be ſo great as to ſuſtain 31 inches of quickſilver, the correction for the difference of temperature will be juſt $\frac{1}{30}$th part more than that for 30 inches; at 25 inches it will be ^{5}ths; at 20 inches $\frac{2}{3}$ds; at 15 inches $\frac{1}{2}$; and at 10 inches only $\frac{1}{3}$d of that deduced from experiment."

This reaſoning, however, is not quite correct; for when the original column of quickſilver is leſs than 30 inches, a greater vacuum will remain in the upper part of the tube, and a ſmaller quantity of quickſilver remains in the lower part by F. Balfour, Eſq. During the month of April, beginning from ſix o'clock in the morning, the barometer roſe a little during four hours, then fell during eight hours; after which it roſe again during

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part of it, in which caſe the ſuppoſed vapour, which is extricated from the mercury by the heat, is leſs in quantity, and finds a greater ſpace to expand itſelf in; therefore the irregularity of apparent expanſion, which is occaſioned by this vapour, is not ſo great as when the column of quickſilver in the barometer is 30 inches; ſo that if the experiments were performed with a column of 15 inches, the expanſions would not come out exactly the halves of thoſe which are ſtated in the table, which are the reſults of experiments performed with a colum of twice 15, viz. 30 inches; the difference however, would not be very conſiderable.

In order to apply the correction for the expanſion, we muſt find, by means of the preceding table, what the column of mercury would be if the quickſilver of the barometer had been at the temperature of 32°. inſtead of its actual temperature. For this purpoſe the actual temperature of the mercury, which is aſcertained by means of the thermometer, muſt be found out in the firſt column of the table, and oppoſite to it is the expanſion for a column of 30 inches, or its bulk at that temperature. Then ſay, as this bulk is to 30 inches, ſo is the obſerved altitude of the mercury in the barometer, to a fourth proportional, which is the corrected altitude. Thus, if the obſerved altitude be 28 inches, and the temperature of the mercury be 72°. you will find 30,1302 againſt 72°. in the table; therefore ſay, as 30,1302 : 30 : : 28 : to a fourth proportional, which is 27,879 ing four hours, and then fell during the laſt 8 hours of the 24. And this took place every day regularly, with very few exceptions.

But it ſeems, that thoſe regular fluctuations of the barometer at Calcutta could not be owing to the immediate action of the moon, ſince the moon could not croſs the meridian every day at the ſame time. So that upon the whole it appears that we have very little, if any, proof of the exiſtence of a diurnal flux and reflux of the atmoſphere, ſimilar to the tides of the ſea; yet the cauſes which render the diurnal tide of the atmoſphere inſenſible to us, may be the elaſticity of the air, and the interference of the much more powerful effects of heat, cold, vapours, &c.

Having thus given a ſufficient idea of the nature and extent of the atmoſphere, and of the uſe of the barometer, I ſhall conclude this chapter with a liſt of the altitudes of ſeveral remarkable mountains, hills, and other places, which have been aſcertained by various ingenious perſons, either geometrically or by means of

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27,879 inches; ſo that had the temperature of the mercury in the barometer been 32°. the obſerved barometrical altitude would have been not 28, but 27,879 inches.—If the degree of temperature be not mentioned in the table, then we muſt take a proportional part of the difference of the contiguous expanſions in the third column of the table, and muſt add it to the expanſion next below; for the ſum will be of barometrical obſervations. I have, however, preferred the reſult of the geometrical meaſurement to that of the barometrical, for all thoſe places which have been meaſured by both means.

TABLE *of* HEIGHTS, *expreſſed in Engliſh Feet, as determined by M. De Luc, Sir George Shuckburgh, Col. Roy, Mr. Bouguer, and other ſcientific Perſons.*

[N. B. The letter G, which follows ſome of the names, means that ſuch altitude was meaſured geometrically.]

In AMERICA.	Above the Ocean.
Chimboraçon	19595
Cayambourow	19391
Antiſana	19290
Pichinha	15670
City of Quito	9377
In AFRICA.	
Table Mountain at the Cape of Good Hope	3454
Gondar City, in Abyſſinia	8440
Pic of Teneriffe (by De Borda, 11022 feet high)	14026
Pic Ruivo in Madeira	5141

In

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be the actual bulk of a column, which at 32°. would be 30 inches high.

Thus if the obſerved altitude be 28 inches, and the temperature 47°. then 47°. is not to be found in the table; but 47°. is equally diſtant from 42°. and 52°. which are in the table;

In EUROPE.	Above the Mediterranean.
The ſummit of Mont Blanc, the higheſt of the Alps, and, as Sir George Shuckburgh ſuppoſes, the moſt elevated point in Europe, Aſia, and Africa. G. — — —	15662
It ſtands 14432 feet above the Lake of Geneva. G.	
Monte Roſa, being the ſecond mountain of the Alps. G. — —	15084
Chamouny, ground-floor of the inn near the foot of Mont Blanc — —	3367
The lake of Geneva — —	1230
The deepeſt part of the lake of Geneva	837
The greateſt depth of the lake being 393 feet.	
Aiguille d'Argentière. G. — —	13402
The ſummit of the Glaciere de Buet. G.	10124
The Dole, higheſt point of Mont Jura. G. — — —	5523
Pitton, higheſt point of Mont Saleve. G.	4514

Summit

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table; therefore we take the half of the difference of the expanſions for thoſe degrees, viz. the half of 0,0328, which is 0,0164, and add it to 30,0333; the ſum 30,0497 is the bulk anſwering to 47°. Then we proceed as before, viz. ſay as 30,0497 : 30 : : 28 : to a fourth proportional, &c.

Notwithſtanding the great accuracy of Col. Roy's experiments, it is believed that his ſtatements of the expanſions

		Above the Mediterranean.
Summit of the Mole — —		6113
St. Joire, in a field at the foot of the Mole. G. — — —		1901
The ſource of the river Arviron, at the bottom of the Vallée de Glace —		3656
The ball on the higheſt, or ſouth-weſt, tower of St. Peter's church in Geneva (249 feet above the lake) G.		1479
Frangy, at the inn, firſt-floor, below the lake of Geneva —	166	
Aix, à la ville de Genève, firſt-floor, below the lake of Geneva	378	
Chambery, au St. Jean Baptiſte, firſt-floor, below the lake of G.	352	
Aiguebelle, at the inn, firſt-floor, below the lake of Geneva —	190	
La Chambre, at the inn, firſt-floor, above the lake of Geneva —	337	
St. Michael, at the inn, firſt-floor, above the lake of Geneva —	1113	2343
Modane, at the inn, firſt-floor, above the lake of Geneva —	2220	3450

Monte

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are rather too great, and that the mean expanſion of an inch of mercury for each degree of Fahrenheit's thermometer, between 20°. and 70°. (within which extremes moſt barometrical obſervations are made) is 0,000102 of an inch. But it is highly probable that different ſpecimens of mercury follow different rates of expanſion. Admitting then the laſt-mentioned expanſion, we derive therefrom an eaſier method of

	Above the Mediterranean.
Monte Viſo. G. — — —	9997
Lannebourg, the foot of Mont Cenis, at the inn, firſt-floor — —	4408
Mont Cenis, at the poſt — —	6261
The ſummit of Mont Cenis — —	9212
Novaleſe, at the foot of Mont Cenis, on the ſide of Italy, at the inn, firſt-floor — — —	2741
Pic de los Reyes, one of the Pyrennées	7620
Pic du Medi, one of the Pyrennées -	9300
Pic d'Oſſano, one of the Pyrennées -	11700
Canegou, one of the Pyrennées — -	8544
Turin, à l'Hotel d'Angleterre, ſecond-floor — — — —	941
Piacenza, St. Marco, firſt-floor — -	263
Parma, au Paon, firſt-floor — —	307
Bologna, au Pelerin, firſt-floor — -	399
Loiano, a little village on the Appenines, between Bologna and Florence	2591
The mountain Raticoſa — —	2901

The

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of correcting the altitude, viz. a method which does not require a table. For this purpoſe we multiply the inches of obſerved barometrical altitude by 0,000102, and multiply that product by the difference of degrees between 32°. and the actual temperature of the mercury; then we add the laſt product to the obſerved barometrical altitude, when the temperature of the mercury is above 32°. or ſubtract it from that altitude when the temperature is below 32°. and the ſum or remainder is the corrected altitude.

Thus,

	Above the Mediterranean.
The ſummit of Monte Velino, one of the Appenines, covered with ſnow in June; about 46 geographical miles, N.W. of Rome, and which is probably the higheſt of the Appenines. G. — — —	8397
Florence, nel Corſo dei Tintori, 50 feet above the Arno, which was 18 feet below the wall of the quay — —	240
Piſa, *aux Trois Demoiſelles*, ſecond-floor	54½
Siena, *aux Trois Rois*, ſecond-floor -	1066
Redicoffani, at the Poſt, firſt-floor -	2470
Redicoffani, the top of the tower of the old fortification on the ſummit of the rock — — —	3060
Viterbo, *aux Trois Rois*, firſt-floor, on the Ciminus of the Ancients — -	1259
Rome, *nel Corſo*, 61 feet above the Tyber — — — —	94
The river Tyber at Rome — —	33

Places

Thus, uſing the ſuppoſitions of the preceding example, the temperature 72°. exceeds 32°. by 40°; therefore we multiply 28 (which is the obſerved barometrical altitude) by 0,000102, and multiply the product 0,002856 by 40, which produces 0,11424; then ſubtract this laſt product from 28, and the remainder 27,88576 inches, is the corrected barometrical altitude; which differs from the reſult of the other method by about one 500dth part of an inch.

The next conſideration relates to the expanſion of air by heat; and the inveſtigation and application of this expanſion

are

Places in ROME.	Above the Tyber.	Above the Mediterranean.
The top of the Janiculum, near the Villa Spada — —	260	293
Aventine Hill, near the Priory of Malta — — —	117	150
In the Forum, near the Arch of Severus, where the ground is raiſed 23½ feet — —	34	67
Palatine Hill, on the floor of the Imperial Palace — —	133	166
Celian Hill, near the Claudian aqueduct — — —	125	158
Bottom of the canal of the Claudian aqueduct — —	175	208
Eſquiline Hill, on the floor of St. M. Major's church — —	154	187
Capitol Hill, on the weſt-end of the Tarpeian rock —	118	151
The union of the Viminal and Quirinal Hills, in the Carthuſian's church; Diocleſ. Baths	141	174
Pincian Hill, in the garden of the Villa Medici — —	165	198

Top

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are by far the moſt intricate and perplexing particulars of the ſubject; for the air does not only expand irregularly through a progreſſive increaſe of heat; but its expanſibility is different according both to its denſity and to its purity.

The beſt contrived, the moſt extenſive, and the moſt concluſive experiments relative to this expanſibility, were made

	Above the Tyber.	Above the Mediterranean.
Top of the croſs of St. Peter's ch.	502	535
The baſe of the obeliſk, in the centre of the Periſtyle —	31	64
The ſummit of the mountain Soracte, lying about 20½ geographical miles north of Rome. G. —		2271
Mount Veſuvius, in the kingdom of Naples. Mouth of the crater from whence the fire iſſued in 1776 —		3938
Mount Veſuvius, at the baſe of the cone — — — —		2021
Top of the mountain Somma, adjoining to Veſuvius — — —		3738
The ſummit of mount Ætna, in Sicily		10954
Barberino di Valdenſa, between Boggeborni and Tavernelle — —		974
Modena, *a l'Albergo nuovo* — —		214
Montmelian, at 20 feet above the river		811
Pont Beauvoiſin — — —		705

La

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made by the ſame abovementioned gentleman, Col. Roy, afterwards General Roy. The manner of performing thoſe experiments, and their reſults, will be mentioned in a more proper part of this work.

For the preſent purpoſe we ſhall only obſerve, that if the ſtratum of air, which lies between the two ſtations of the barometer, were of an uniform temperature, and of an uniform degree of moiſture; or even if it were of a certain progreſſively increaſing or decreaſing temperature; rules might be

deviſed

	Above the ſea.
La tour du Pin	938
Verpilliere	566
Lyons, at the Hotel Blanc, 50 feet above the Soane	449
St. Jean la Vieux	695
Cerdon, near the poſt-houſe at the foot of the rocks	854
Nantua, 10 feet above the lake	1423
Chatillon, at the *Logis Neuf*	1629
Colonges	1626
St. Genis, apparently on a level with the foot of Mont Jura	1501
Macon, at the Parc, 24 feet above the Soane	514
Dijon, *à la Cloche*, the firſt-floor	710
Auxerre, 50 feet above the river	283
Sens, at the poſt	163
Fontainbleau, at the *Grand Cerf*, ſecond-floor	242
Paris, mean height of the Seine, viz. *quand les eaux ſe trouvent à 13 pieds 9 pouces ſur l'échelle du Pont Royal*, ſelon M. de Lalande	36½

Mr.

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deviſed for correcting the effects of aërial expanſion. However, the practicability of aſcertaining the various but contemporaneous temperature and moiſture of a conſiderable ſtratum of air, ſeems, at leaſt for the preſent, to be utterly out of our power.

In

		Above the Sea.
M. de Lalande's obſervatory, at the College Royal, firſt-floor, above the Seine, at Paris —	101	137 ½
Stone gallery of the church on Mount Valerien, above the Seine, Paris — — —	473	509 ½
Depth of the cave of the Royal Obſervatory at Paris, below the pavement — —	98	
Height of the North Tower of the church of *Notre Dame* at Paris, above the floor. G. —	218 ½	
Chantilly — — —		119
Clermont — — —		329
Amiens, *Rüe de Noyon*, firſt-floor		147
Abbéville, firſt-floor — —		79
Mean height of the river Thames at London (viz. when the water is 15½ feet below the pavement in the left-hand arcade at Buckingham-ſtairs) which is above the mean height of the river Seine at Paris 6,8 —		43

Iron

In the preſent ſtate of knowledge, the only correction we can apply is founded upon the ſuppoſition that the temperature of the whole ſtratum of air, which lies between two ſtations, is the mean of the temperatures of the air at the two ſtations; and that air of the more common degree of moiſture is expanded, at a mean 0,00245 of its bulk, which is

		Above the Sea.
Iron gallery over the Dome of St. Paul's church, in London above the church-yard, North ſide. G.	281	
The top of the croſs on the dome of the ſame, above the ground without	340	
Height of the Pagoda in Kew-gardens. G.	116½	
Warwick, mean level of the river Avon		155
Peak of Snowdon in North Wales		3555
Moel Eilio, North Wales		2371
Whernſide		4050
Pendle-hill		3411
Pennygant		3930
Ingleborough		3987
Halvellyn		3324
Skiddaw		3270
Croſs-fell		3390
Saddleback		3048

Ben-

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is called *one*, by each degree of Fahrenheit's thermometer, between 20°. and 70°. which is the range of temperature through which moſt barometrical obſervations are likely to be made.— The rule then, which is eſtabliſhed upon thoſe ſuppoſitions, is as follows:

Multiply the difference between 32°. and the mean temperature of the air, (viz. the mean between the temperatures of the air, obſerved at the two ſtations) by 0,00245, and multiply

		Above the Sea.
Ben-Moir — — — —		3723
Ben-Laurs — — — —		3858
Ben-Gloe — — — —		3472
Ben-Lomond — — —		3180
Beneviſh — — — —		4350
Shihallion — — —		3461
Tinto — — — —		2342
Calton Hill, above Leith Pier-head, Scotland. G. — —	344	
Arthur's ſeat, above Leith Pier-head, Scotland. G. — —	803	
Baſe of Hawk-hill Obſervatory, above the bottom of the ſmall rock on Arthur's ſeat, Scotland. G. — — —	684	
Mount Hekla in Iceland — —		4887

The

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multiply the product by the approximated perpendicular diſtance, already found, between the two ſtations, and the laſt product muſt be added to, or ſubtracted from (according as the mean temperature of the air is above or below 32°) the approximated altitude; and the ſum or difference is the correct altitude.

For if what we have called the approximated elevation gives the real diſtance between the two ſtations when the mean temperature of the air is 32°. it is evident that when the air is one degree hotter, its bulk is 0,00245 larger; hence in this caſe the ſame weight, or the ſame preſſure on the mercury of the barometer, is produced by a ſtratum of

air

The Caſpian ſea is ſaid (by Mr. Lacre) to be 306 feet below the ocean.

The

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air thicker than the former by 0,00245 of the whole, viz. of the whole number of feet, or fathoms, by which that thickneſs is expreſſed; hence the quantity 0,00245 muſt be multiplied by the number of feet or fathoms, which would expreſs the real thickneſs of the ſtratum if its temperature were 32°.—It is alſo evident, that if one degree of heat increaſes the ſtratum 0,00245 of the whole, two degrees muſt increaſe it of twice that quantity; three degrees, of three times that quantity, &c. Therefore the above-mentioned product muſt be alſo multiplied by the number of the degrees of heat, &c.

Having thus ſhewn the foundation of the method of applying the barometer to the meaſurement of altitudes, in ſeparate parts, for the ſake of perſpicuity, I ſhall now collect all the neceſſary rules under one point of view; which may be conſidered as the ultimate reſult of the inveſtigation.

I. For this purpoſe two accurate barometers, as nearly as poſſible of the ſame conſtruction, muſt be had; and each barometer muſt be furniſhed with a thermometer, which muſt be attached to it in ſuch a manner as to have its bulb in contact, or nearly in contact, with the mercury of the ciſtern of the barometer. Two other ſeparate thermometers muſt likewiſe be provided.

One barometer and a detached thermometer muſt be ſituated at each of the two places, between which the perpendicular diſtance is required to be meaſured; and the obſervations at both places muſt be made by two obſervers, at the very ſame time; obſerving the altitude of the mercury in the barometer, the temperature of its mercury, which is indicated by the attached thermometer, and the temperature

of

The heights of the Aſiatic mountains have not, as far as I know, been meaſured with any tolerable degree of accuracy.

Not-

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of the ambient air, by means of the detached thermometer, which for this purpoſe muſt be ſituated in ſome expoſed place, out of the influence of a fire, of the ſun, &c.—Thoſe two ſets of obſervations muſt be written one under the other, after the manner of the ſubjoined example.

II. Each barometrical altitude muſt be reduced to what it would be, if the temperature were 32°. which may be done two ways, viz. Find in the table of mercurial expanſions, in page 254, the bulk of mercury anſwering to the obſerved temperature of the mercury; then ſay, as that bulk is to 30 inches, ſo is the obſerved barometrical altitude to a fourth proportional, which is to be found by the common rule of three, and is the reduced barometrical altitude in queſtion. Otherwiſe, multiply the conſtant quantity 0,00102, by the inches and decimals of obſerved barometrical altitude, and multiply the product by that number of degrees of heat by which the temperature of the mercury in the barometer differs from 32°. Then add this laſt product to the obſerved barometrical altitude, if the temperature of the mercury exceed 32°.; or ſubtract it from that altitude, if that temperature be leſs than 32°.; and the ſum or difference is the reduced barometrical altitude.—It is evident that when the temperature of the mercury is 32°. no reduction will be wanted.

III. In a table of the logarithms of numbers, wherein the logarithms conſiſt of ſeven places of figures, find the logarithms anſwering to both reduced barometrical altitudes; ſubtract the leſſer from the greater; then the remainder being

Notwithſtanding the ſtupendous altitude of ſome of the abovementioned mountains; it is ſhewn by an eaſy calculation, that the higheſt mountain on the ſurface of the earth does not make ſo great an appearance, with reſpect to the globe of the earth, as a little mountain of a tenth of an inch in height would

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being multiplied by 60000, will give the approximated elevation in feet; or if multiplied by 10000, will give it in fathoms. Both methods come to the ſame thing; but the latter is more expeditious, becauſe the multiplication of the logarithmic remainder by 10000 is done by removing the comma four figures to the right.

IV. Take the mean between the temperatures of the air at both ſtations, which are indicated by the detached thermometers (viz. the half of their ſum); take the difference between this mean, and 32°.; multiply this difference by 0,00245, and multiply the product by the approximated elevation already found. Then add this laſt product to, or ſubtract it from, the approximated elevation, according as the mean temperature of the air is above or below 32°.; and the ſum or difference is the correct perpendicular diſtance between the two ſtations.

But this correction for the expanſion of the air may be rendered more exact by the uſe of the following table; viz. take the mean of the corrected barometrical altitudes, and the mean temperature of the air; find out thoſe quantities, or the neareſt to them, in the upper and in the left-hand columns of the table, and in the place which ſtands juſt under the one, and level with the other, you will find the expanſion which muſt be uſed inſtead of the abovementioned would make upon a globe of two feet in diameter. This calculation is made by ſaying, as the diameter of the earth is to the altitude of the higheſt mountain, ſo is a diameter of two feet to a fourth proportional, which being found by the rule of three, is the height of a ſimilar mountain on a globe of two feet in diameter.

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mentioned conſtant quantity 0,00245, viz. it muſt be multiplied by the difference of degrees between 32°. and the mean temperature of the air, as alſo by the approximated elevation, &c. as mentioned in the preceding paragraph.

N. B. There are ſome other ways of performing this problem, and of applying the corrections; but I have preferred the above as being the moſt accurate; and more evidently deduced from the foregoing principles.

Mean Expanſion of common air for each degree of Fahrenheit's Thermometer between 12°. and 92°. and under different preſſures, as indicated by the height of the mercury in the barometer, from 19 to 30 ½ inches.

Altitude of the mercury in the barometer, in inches.	12°.	22°.	32°.	42°.	52°.	62°.	72°.	82°.	92°.
19.	0,00133	0,00139	0,00144	0,00149	0,00155	0,00152	0,00149	0,00144	
20.	0,0016	0,00167	0,00173	0,0018	0,00187	0,00183	0.0018	0,00173	
21.	0,0016	0,00167	0,00173	0,0018	0,00187	0,00183	0,0018	0,00173	
22.	0,0016	0,00167	0,00173	0,0018	0,00187	0,00183	0,0018	0,00173	
23.	0,00188	0,00195	0,00203	0,0021	0,00218	0,00214	0,0021	0,00203	
24.	0,00188	0,00195	0,00203	0,0021	0,00218	0,00214	0,0021	0,00203	
25.	0,00188	0,00195	0,00203	0,0021	0,00218	0,00214	0,0021	0,00203	
26.	0,00197	0,00205	0,00213	0,00221	0,00229	0,00225	0,00221	0,00213	
26,5	0,00201	0,00209	0,00218	0,00226	0,00234	0,0023	0,00226	0,00218	
27.	0,00206	0,00214	0,00222	0,00231	0,00239	0,00235	0,00231	0,00222	
27,5	0,0021	0,00219	0,00227	0,00236	0,00245	0,0024	0,00236	0,00227	
28.	0,00215	0,00224	0,00232	0,00241	0,0025	0,00245	0,00241	0,00232	
28,5	0,00219	0,00228	0,00237	0,00246	0,00255	0,00251	0,00246	0,0023	
29.	0,00224	0,00233	0,00242	0,00251	0,0026	0,00256	0,00251	0,00242	
29,5	0,00228	0,00238	0,00247	0,00256	0,00266	0,00261	0,00256	0,00247	
30.	0,00233	0,00242	0,00252	0,00261	0,00271	0,00266	0,00261	0,00252	
30,	0,00237	0,00247	0,00257	0,00266	0,00276	0,00271	0.00266	0,00257	

Example I. It is required to determine the perpendicular diſtance between the ſummit and the foot of a hill, from the following obſervations:

	Altitude of the barometer.	Temperature of mercury.	Temper^{e}. of air.
At the foot of the hill	29,561 inches	63°	56°
At the ſummit of the hill	28,272 inches	54°	48°

From the table in page 254, we find the bulk of mercury for 63°. equal to 30,1; therefore 30,1 : 30 : : 29,561 : to the reduced barometrical altitude, 29,462.

The bulk of mercury for 54°. is, from the table, 30,0726; therefore 30,0726 : 30 : : 28,272 : to the reduced barometrical altitude, 28,204.

The logarithm of 29,462 is 1,4692622
The logarithm of 28,204 is 1,4503107

The difference of thoſe log. is 0,0189515

Now if the comma be removed four places towards the right hand, this remainder will expreſs the approximated elevation in fathoms; viz. 189,515 fathoms. Or if it be multiplied by 60000, it will expreſs the ſame approximated elevation in feet, viz. (0,0189515 × 60000 =) 1137,09 feet.

The mean temperature of the air is $\left(\frac{56^\circ+48^\circ}{2}=\right)$ 52°. which exceeds 32° by 20°; therefore (0,00245 × 20 × 1137,09 =) 55,71741, which, ſince the mean temperature of the air is above 32°, muſt be added to the approximated elevation, and their ſum, viz. (1137,09 + 55,71741 =) 1192,80741 feet, is the correct elevation, or the perpendicular altitude of the hill.

For the ſake of greater accuracy, the expanſion of the air may be taken from the preceding table, according to the laſt part of the rule; viz. the mean between the reduced barometrical altitudes is $\left(\frac{29{,}462\ +\ 28{,}204}{2}=\right)$ 28,833; and the

the mean temperature of the air is 52°. Then in the table we find facing 28,5, which is the neareſt to 28,833; and under 52°, or properly under the degrees of heat between 52°. and 62°. the quantity 0,00255, which quantity muſt be uſed inſtead of 0,00245; therefore (0,00255 × 20° × 1137,09 =) 57,99159, which being added to the approximated elevation, gives (1137,09 + 57,99, &c. =) 1195,08 feet for the altitude of the hill, which is a nearer approximation to the truth.

Example II. It is required to determine the perpendicular altitude between two ſituations, where the following obſervations were made.

	Bar. altit.	Att. Therm.	Det. Ther.
Lower place - -	29,883 - -	28°. - -	24°.
Upper place - -	29,032 - -	26°. - -	26°.

From the table in page 254, we have the bulk of mercury for 28°. equal to 29,9865; therefore ſay, 29,9865 : 30 : : 29,883 : to the reduced barometrical altitude 29,897.

Alſo the bulk of mercury for 26°. is 29,98; therefore ſay, 29,98 : 30 : : 29,032 : to the reduced barometrical altitude 29,051.

The logarithm of 29,897 is 1,4756276
The logarithm of 29,051 is 1,4631611

The difference of thoſe log^s. is 0,0124665, which, by removing the comma four places to the right, expreſſes the approximated elevation in fathoms, viz. 124,665 fathoms. Or if multiplied by 60000, will expreſs it in feet, viz. (0,0124665 × 60000) 747,99 feet.

The mean temperature of the air is $\left(\frac{24^\circ + 26^\circ}{2} =\right)$ 25°, which is leſs than 32°. by 7°. therefore $(0{,}00245 \times 7^{\circ} \times 747{,}99 =)$ 12,828 muſt be ſubtracted from the approximated elevation, and the remainder 735,161 feet, is the correct perpendicular altitude in queſtion.

Otherwiſe, inſtead of the quantity 0,00245, the expanſion of the air may be taken from the table in page 273. Thus the mean between the reduced barometrical altitudes is $\left(\frac{29{,}897 + 29{,}051}{2} = \right)$ 29,474; and the mean temperature of the air is 25°. Then in the table we find, facing 29,5, which is the neareſt to 29,474, and under 25°. the quantity 0,00238. Therefore $(0{,}00238 \times 7^{\circ} \times 748 =)$ 12,46168 muſt be ſubtracted from the approximated elevation; ſince the mean temperature of the air is below 32°. And the remainder, viz. $(747{,}99 - 12{,}46168 =)$ 735,53 is the correct perpendicular altitude between the two ſituations.

Example III. Let the barometrical obſervations made at two places, be 28,65, and 29,9. Alſo let the temperature of the mercury and of the air at both places, be 32.

The perpendicular diſtance between thoſe two places, is thereby eaſily determined, ſince in this caſe no correction needs be made for temperature.

The logarithm of 29,9 is 1,4756712
The logarithm of 28,65 is 1,4571246

The difference of thoſe log^{s}. is 0,0185466, which ſhews, that the perpendicular diſtance in queſtion is 185,466 fathoms, or 1112,796 feet.

After all, it muſt be acknowledged, that notwithſtanding the greateſt exertions of ſeveral ingenious perſons, the method of meaſuring altitudes by means of barometrical and thermometrical obſervations, has not yet attained a degree of perfection ſufficient to ſuperſede the geometrical, or trigonometrical, meaſurements.

The facility and expedition with which the former is performed, renders it uſeful whenever no very great degree of accuracy is required; for in general the barometrical method gives the perpendicular diſtance within about one eightieth part of the truth; for inſtance, if the altitude given by the barometer be 560 feet, the error or deviation from the true altitude, may amount to about 7 feet.

Several altitudes, which had been purpoſely and accurately meaſured by geometrical means, were afterwards repeatedly meaſured by means of barometrical obſervations; but the reſults of the latter were found to diſagree more or leſs from thoſe of the former method. The following is an example of this ſort, which I have taken from Col. Roy's paper in the 67th vol. of the Philoſophical Tranſactions.

The perpendicular diſtance between two places, having been meaſured geometrically, was found equal to 730,8 feet. The ſame was afterwards meaſured with all poſſible accuracy, and at different times, by means of barometers, &c. and the reſult was, at one time 721,8 feet; at a ſecond time it was 734,6 feet; a third time it was 733,9 feet; and a fourth time it was 748,4 feet; the mean of which reſults is 734,7 feet.—It is evident that the true or geometrical meaſurement differs from every one of thoſe reſults, as well as from their mean.

This diſagreement, undoubtedly, depends upon the varying gravity, and the varying expanſibility, of air; whence ariſes the difficulty of aſcertaining the real mean expanſibility of the ſtratum of air which lies between the two places of obſervation. The air at different altitudes is loaded with different quantities of moiſture; hence its expanſibility is not exactly the ſame in any two places. Beſides, both the moiſture and the ſpecific gravity of the air differ at different times; nor do we know how to aſcertain thoſe quantities at different altitudes.

It is alſo neceſſary to obſerve, that in different latitudes neither the gravity nor the expanſibility of air is the ſame. Hence the ratio of the gravity of air to that of mercury is by no means conſtant; nor is it eaſily aſcertained for any particular place and time. In the province of Quito in Peru, which ſtands conſiderably above the level of the ocean, the altitudes which are deduced from barometrical obſervations, fall greatly ſhort of the real or geometrical menſurations; whereas at Spitzbergen, they greatly exceed the truth. "It ſeems," *as Col. Roy juſtly obſerves*, "that the atmoſphere ſurrounding our globe might poſſibly "be compoſed of particles, whoſe ſpecific gravities were "really different; that the lighteſt were placed at the "equator, and that the denſity of the others gradually in-"creaſed from thence towards the poles, where the heavieſt "of all had their poſition."

This ſuppoſition is corroborated by two obvious conſiderations, namely, that on account of the cold the air about the poles of the earth is much dryer than in other places, and that on account of the polar diameter being ſhorter than the equatorial diameter, the air which lies at equal diſtances from the ſurface of the earth, is actually nearer to the centre of attraction about the poles than about the equator. We may therefore conclude, upon the whole, that in order to render the barometrical meaſurement capable of greater accuracy than it is at preſent, farther experiments and obſervations muſt be made with all poſſible attention, in different latitudes, and in different ſtates of the atmoſphere. It is alſo probable that it will be found uſeful to accompany with the barometer and thermometer, the uſe of other inſtruments, ſuch as the hygrometer, the electrometer, and the manometer.

Thoſe perſons who wiſh to examine this ſubject in a more particular manner, may conſult the following valuable publications: M. de Luc's *Recherches ſur les Modifications de l'Atmoſphere*. Dr. Horſley's Paper in the Philoſophical Tranſactions, vol. 64th. Sir George Shuckburgh's Paper, M. de Luc's Paper, and Col. Roy's Paper, all three in the 67th vol. of the Philoſophical Tranſactions. Alſo the article *Pneumatics* in the Encyclopædia Britannica.

CHAPTER X.

OF AIR IN MOTION, OR OF THE WIND.

THE weight and preſſure of the atmoſpherical air have been explained in the preceding chapters. It is now neceſſary to examine the particulars which relate to the motion of the ſame fluid, and thoſe particulars may be arranged under two principal denominations, viz. of *wind*, and of *ſound*.

Wind, or a current of air, is the progreſſive motion of air from one place to another. Sound, or the ſenſation which we perceive through our ears is produced by a vibratory motion of the ſounding body, and is conveyed to the ear by a vibratory motion of the particles of air, or other body which intervenes between the ſounding body and the ear.

The particles of air in that caſe move a ſhort way backwards or forwards from their reſpective ſituations, and at the end of every other vibration, are to be found preciſely at their original ſituations.—What relates to ſound will be treated of in the next chapters; but the progreſſive movements of air will be examined in the preſent.

The theory of thoſe movements may be comprized into four principal propoſitions; the firſt of which is to determine the velocity with which air of the uſual denſity on the ſurface of the earth, or of any denſity, will ruſh into a vacuum through a given aperture; the ſecond is to determine the velocity with which air of a certain denſity will ruſh into a veſſel containing air of leſs denſity; the third is to determine the velocities of the natural currents of air, or of the winds; and the fourth is to determine the reſiſtance which the air in motion offers to ſolids of a given ſize, or the reſiſtance which the latter meet with in moving through the air.

Both the theoretical propoſitions, and the cauſes which render the reſults of the experiments different from thoſe of the theoretical propoſitions in the movements of water, and other non-elaſtic fluids, bear a great degree of analogy to what may be ſaid with reſpect to the movements of air and other permanently elaſtic fluids, excepting when elaſticity is concerned; hence, having been rather particular in our explanation of the former, we may be be allowed to be more conciſe in treating of the latter.

I. If we conſider air in its natural ſtate, viz. preſſed by the weight of the atmoſphere, we may calculate the velocity with which it will ruſh into a vacuum through any aperture, by conſidering it as a non-elaſtic fluid; but then we muſt take for its altitude, the altitude of an homogeneous atmoſphere, viz. ſuch an altitude as is equivalent to the natural decreaſing altitude of the whole atmoſphere (ſee the note in page 246). Thus, when the ſpecific gravity of air is 0,0013, the altitude of an homogeneous atmoſphere may be reckoned equal to 26058 feet. Then ſince the velocities, which are acquired by falling bodies, are as the ſquare roots of the ſpaces; therefore (agreeably to what has been ſaid in page 160, and following, of this Second Part) the velocity with which air of the uſual denſity will ruſh into a vacuum near the ſurface of the earth, is that which a body would acquire by falling from the height of 13029 feet, which is the half of 26058; namely, the velocity of 1292 feet per ſecond. But this velocity is altered by heat and cold, ſince the altitude of an homogeneous atmoſphere is thereby increaſed or diminiſhed. It is to be obſerved, however, that the variation, which ariſes not from a change of temperature, but that which is indicated by the barometer alone, will not alter the height of an homogeneous atmoſphere, and of courſe neither will it alter the above-

above-mentioned velocity; becauſe that variation is attended with a proportionate denſity of the atmoſphere.

II. The velocity with which air of the uſual denſity will ruſh into a veſſel containing air leſs denſe, may alſo be eaſily calculated; for in this caſe, we muſt conſider the air as preſſed not by the whole atmoſphere, but by the difference between the whole atmoſphere, and that part of it which produces the denſity of the air in the veſſel. Or, in other words, the altitude of an homogeneous atmoſphere muſt be reduced in the proportion of the uſual denſity of the air at the ſurface of the earth, to the denſity of the air in the veſſel; the reſt of the calculation proceeds exactly as in the preceding caſe. The velocity, however, which is obtained by this means, will be gradually checked and diminiſhed, becauſe by the entrance of the external air, the quantity, and, of courſe, the denſity of the air in the veſſel, is gradually increaſed.

The like calculations may be eaſily and evidently applied to the entrance of air, which is preſſed by any given preſſure greater or leſs than that of the whole atmoſphere; as alſo to the efflux through a given aperture, of air, which has been confined in a given veſſel by a given weight. But in practice, both the influx and the efflux of air into, or out of, a given veſſel through a given aperture, turn out by much different from the determinations of the theoretical calculations; which is owing to the ſame concurring and fluctuating cauſes, as have in chap. VII. of this Part, been ſhown to affect the movements of non-elaſtic fluids, viz. the attraction of aggregation, the attraction of coheſion, the formation of the *vena contracta*, in certain caſes, the want, or the aſſiſtance, of an ajutage or ſhort pipe to the aperture, the different directions which different parts or filaments of fluid acquire in their motion, the friction, &c. And in elaſtic fluids ſuch variations muſt evidently be greater than in water, and other non-elaſtic fluids.

The ſame obſervations may be made with reſpect to the paſſage of air, and other elaſtic fluids, through long pipes, channels, &c. which retard its velocity in a very great degree, and the irregularity is ſo great, that no known theory is ſufficient to determine the effect in moſt caſes.

The quantity of air diſcharged into the atmoſphere, through a given aperture in a veſſel, wherein the air is preſſed by a given weight, as appears from Dr. Young's Experiments, ſeems to be nearly as the ſquare-root of the preſſure; and that the ratio of the expenditures by different apertures, with the ſame preſſure, lay between the ratio of their diameters, and that of their areas *.

III. The velocity and the force of the wind, or of a natural current of air, deſerve to be examined

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* Philoſophical Tranſactions for 1800. P. I.

with all poſſible attention; it being owing to that current that we are enabled to navigate the ocean, to make uſe of windmills, &c. But the obſtruction which the motion of air receives from the various cauſes that have been mentioned in ſpeaking of non-elaſtic as well as of elaſtic fluids, in the IVth and in the preſent Chapter of this Second Part of theſe Elements, invalidates the application of every theory, and renders the reſults of actual experiments the only guides which can direct us in the uſe and application of the winds.

The velocity of air in natural currents of certain denominations, has been attempted to be meaſured by various means. It has been attempted by meaſuring the velocities of the ſhadows of clouds upon the ſurface of the earth; but this method is very fallacious: firſt, becauſe it is not known whether the clouds do or do not move exactly with the air in which they float; and ſecondly, becauſe the velocity of the air at the region where the clouds are, is by no means the ſame as that of the air which is nearer to the ſurface of the earth, and ſometimes is quite contrary to it, which is indicated by the motion of the clouds themſelves.

The beſt method of meaſuring the velocity of the wind is by obſerving the velocity of the ſmoke of a low chimney, or to eſtimate it by the effect it produces upon certain bodies.

IV. Whatever has been ſaid in Chap. IV. of the preſent Second Part of theſe Elements, is ſo evi-

dently

dently applicable to the impulſe which air in motion gives to ſolids, or to the obſtruction which ſolids receive in their movements through air; that it would be needleſs in this place to dwell any longer upon the theoretical part of the ſubject.

The beſt method of eſtimating the force as well as the velocity of the wind, is from the effects which it produces upon certain bodies. The inſtruments which have been found to anſwer theſe purpoſes in the beſt manner, will be deſcribed hereafter; but for the preſent we ſhall obſerve, that from the concurrence of the experiments which have been made with various inſtruments and different methods, the following eſtimate has been deduced; namely, that in currents of air of the denominations which are expreſſed in the fourth column of the following table, the air moves at the rate of ſo many feet per ſecond as are expreſſed in the ſecond column, or of ſo many miles per hour as are expreſſed in the firſt column. The third column expreſſes in avoirdupoiſe pounds, the force of the wind on an area of one foot ſquare, which is preſented in a direction perpendicular to it.

This table was firſt publiſhed in the 51ſt volume of the Philoſophical Tranſactions, by Mr. J. Smeaton, the celebrated engineer, who, in his valuable Paper on the natural powers of water and wind, introduces it with the annexed paragraph.

" The following table, which was communicated " to me by my friend Mr. Rouſe, and which ap-" pears

"pears to have been conſtructed with great care, "from a conſiderable number of facts and experi- "ments, and which having relation to the ſubject "of this article, I here inſert it as he ſent it to "me; but at the ſame time muſt obſerve, that "the evidence for thoſe numbers, where the velo- "city of the wind exceeds 50 miles an hour, do "not ſeem of equal authority with thoſe of 50 "miles an hour and under. It is alſo to be ob- "ſerved, that the numbers in the third column are "calculated according to the ſquare of the velocity "of the wind, which in moderate velocities, "from what has been before obſerved, will hold "very nearly*."

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* The propoſition upon which the third column has been calculated, ſeems to be, that the impulſe of a current of air, ſtriking perpendicularly upon a given ſurface, with a certain velocity, is equal to the weight of a column of air which has that ſurface for its baſe, and for its height the ſpace through which a body muſt fall, in order to acquire that velocity of the air.

Velocity of the Wind.		Perpendicular force on one foot area, in pounds avoirdupoiſe.	
Miles in one hour.	Feet in one ſecond.		
1	1,47	0,005	Hardly perceptible.
2	2,93	0,020	Juſt perceptible.
3	4,40	0,044	
4	5,87	0,079	Gentle pleaſant wind, or breezes.
5	7,33	0,123	
10	14,67	0,492	Pleaſant briſk gale.
15	22,00	1,107	
20	29,34	1,968	Very briſk.
25	36,67	3,075	
30	44,01	4,429	High winds.
35	51,34	6,027	
40	58,68	7,873	Very high.
45	66,01	9,963	
50	73,35	12,300	A ſtorm, or tempeſt.
60	88,02	17,715	A great ſtorm.
80	117,36	31,490	A hurricane.
100	146,70	49,200	A hurricane that tears up trees, carries buildings before it, &c.*

When the direction of the wind is not perpendicular, but oblique to the ſurface of the ſolid, then the force of the former upon the latter will not be ſo great as when the impulſe is direct, and that for

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* The velocity of the wind in very great ſtorms is ſo very uncertain, that the eſtimates given by different perſons are very far from agreeing with each other. *Mariotte* reckoned it at 34 feet per ſecond; *Derham* at 66 feet per ſecond; and *de la Condamine* at 90 ½ feet per ſecond.

reaſons which are eaſily derived from the theory of the reſolution and compoſition of forces, and from the theory of direct and oblique impulſes which have been delivered in the Firſt Part of theſe Elements; alſo from what has been ſaid in the IVth Chapter of this Second Part. In ſhort, the general propoſition for compound impulſes is, that — *The effective impulſe is as the ſurface, as the ſquare of the air's velocity, as the ſquare of the ſine of the angle of incidence, and as the ſine of the obliquity of the ſolid's motion to the direction of the impulſe, jointly*; for the alteration of every one of thoſe quantities will alter the effect in the ſame proportion. But thoſe general rules, as we have already more than once obſerved, are ſubject to great variations; ſo that their reſults ſeldom coincide with thoſe of actual experiments. In the motion of ſolids through air, a great retardation ariſes (beſides other cauſes) from the condenſation of the air before the ſolid, and from the rarefaction, and, with ſome velocities, the vacuum, which is formed behind the ſolid; hence nothing but actual experiments can poſſibly illuſtrate this ſubject*. Winds

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* See Derham's Paper on the Velocity of Sound. Philoſophical Tranſactions Abridged, vol. IV. Robins's Treatiſe on Gunnery. De Borda's Experiments, in the Memoirs of the Academy of Sciences for 1763. Smeaton's Paper in the Philoſophical Tranſactions, vol. 51ſt. But a great many more experiments muſt be inſtituted by ſcientific perſons before the ſubject can be ſufficiently elucidated.

are of great uſe to us; but in the application of the winds to navigation, to wind-mills, and to other machines, ſome other circumſtances muſt likewiſe be had in view; namely, the probable force, duration, and direction, of the wind which is likely to blow in any given place. Theſe particulars muſt be derived from the hiſtory of countries, or from meteorological journals, viz. from long and accurate experience.

It appears that almoſt in all expoſed ſituations, ſuch as the open ſea, extenſive plains, tops of hills, &c. the wind almoſt always prevails; and few indeed are the days, or the hours, throughout the year, in which a real, or what is called a dead, calm is to be obſerved.

In thoſe places for more than three quarters of the year (I do not mean without interruption) the force of the wind is ſufficient to work a nicely made wind-mill, or at leaſt to impel the ſails of a ſhip.

The wind machines of larger ſize and greater power, which are applied to pumps for extracting water from deep pits, which are applied to the grinding of hard materials, &c. require a higher wind to put them in motion. Dr. Stedman was informed by a gentleman of experience, who had erected a wind-machine to drain his coal-pit, that he never could depend upon more than 53 or 54 hours of wind ſufficient for moving that machine in a week, taking the year round. Dr. Stedman himſelf, from a careful inſpection of a column for the wind in a meteorological journal, endeavoured to form a proportion between the duration of wind of a certain degree, and that of another degree.

"From this computation," *he ſays*, "we have "2,592 days in a week, or 19,307 weeks in a "year, in which wind machines of the heavier "kind, and of conſiderable friction, may be ſup- "poſed to be kept in motion; which, to the times "wherein they cannot go, is as 10 to 17."

But the journal upon which he grounded his proportion, was the journal of a ſingle place; the period of years, as he juſtly obſerves, was too ſhort; the proportion for the different months of the ſame name in different years, as alſo the proportion for the different years, as appears from the tables he has given, are too fluctuating and irregular; to which we may add, that the meteorological journals in general, wherein one or two obſervations are ſtated for every 24 hours, do not afford materials ſufficient for an accurate eſtimate*.

The direction of the wind, which is various in moſt countries, and varies in the ſame country, acquires its different denominations from the four principal quarters, or cardinal points of the world. Thus it is called *North wind*, when it blows from the north towards the ſouth; it is called *Eaſt wind*,

when

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* See Dr. Stedman's Paper in the 67th volume of the Philoſophical Tranſactions.

when it blows from the eaſt towards the weſt; it is called *South wind*, when it blows from the ſouth towards the north, and *Weſt wind*, when it blows from the weſt towards the eaſt.

The winds which deviate a little from the cardinal points, are commonly called *northerly*, *eaſterly*, *ſoutherly*, and *weſterly*, winds. But for the ſake of greater diſtinction, the ſpace or arch which lies between any two contiguous cardinal points, is ſuppoſed, by the mariners, to be divided into eight equal parts, or *points*, and each point into four equal parts, called *quarter-points*. So that the horizon is ſuppoſed to be divided into 32 principal points, which are called *rhumbs*, or *winds*, to each of which a particular name is aſſigned; and thoſe names are derived from the names of the adjacent cardinal points, as is ſhewn by the following table, wherein the names of all the 32 points are arranged in order from the north, eaſtward, &c. but thoſe names are generally expreſſed ſimply by their initials. Thus, N. ſtands for north; S. E. ſtands for ſouth-eaſt, &c.

North
North by Eaſt
North North Eaſt
North Eaſt by North
North Eaſt
North Eaſt by Eaſt
Eaſt North Eaſt
Eaſt by North

Eaſt
Eaſt by South
Eaſt South Eaſt
South Eaſt by Eaſt
South Eaſt
South Eaſt by South
South South Eaſt
South by Eaſt

South
South by Weſt
South South Weſt
South Weſt by South
South Weſt
South Weſt by Weſt
Weſt South Weſt
Weſt by South
Weſt
Weſt by North
Weſt North Weſt
North Weſt by Weſt
North Weſt
North Weſt by North
North North Weſt
North by Weſt.

Almoſt in every country, the wind is more or leſs predominant in a particular direction; but before we begin to enumerate the obſervations which have been made relatively to thoſe directions, it will be proper to mention the cauſes, which, as far as we know, produce the wind, in order that the reader may be enabled in ſome meaſure to comprehend the reaſons of the particular directions, which will be mentioned in the ſequel.

Heat, which rarefies, and cold which condenſes, the air, are by far the principal, and more general, cauſes which are productive of a current of air; and the greateſt general heat or cold is derived from the preſence or abſence of the ſun.

The next cauſe has been juſtly attributed to the attraction of the ſun and moon, whoſe influence is ſuppoſed, with great probability, to occaſion a tide, or flux and reflux, of the atmoſpherical fluid, ſimilar to that of the ſea, but greater, becauſe the air lies nearer to thoſe celeſtial bodies, and becauſe air is incomparably more expanſible than water.

It has been calculated by D'Alembert from the general theory of gravitation, that the influence of the ſun and moon in their daily motions, is ſufficient to produce a continual eaſt wind about the equator. So that upon the whole we may reckon three principal daily tides, viz. two ariſing from the attractions of the ſun and moon, and the third from the heat of the ſun alone: all which ſometimes combine together, and form a prodigious tide.

In corroboration of the opinion of the influence of the ſun, and principally of the moon, in the production of wind, we muſt likewiſe mention the obſervations of Bacon, Gaſſendi, Dampier, Halley, &c. namely, that the periods of the year moſt likely to have high winds, are the two equinoxes; that ſtorms are more frequent at the time of new and full moon, eſpecially thoſe new and full moons which happen about the equinoxes; that, at periods otherwiſe calm, a ſmall breeze takes place at the time of high water; and that a ſmall movement in the atmoſphere is generally perceived a ſhort time after the noon and the midnight of each day.

Some action in the production of wind may alſo be derived from volcanoes, fermentations, evaporations, and eſpecially from the condenſation of vapours: for we find that, in rainy weather, a conſiderable wind frequently precedes the approach of every ſingle cloud, and that the wind ſubſides as ſoon as the cloud has paſſed over our zenith.

Wherever any of the above-mentioned cauſes is conſtantly more predominant, as the heat of the ſun within the tropics, there a certain direction of the wind is more conſtant; and where different cauſes interfere at different and irregular periods, as in thoſe places which are conſiderably diſtant from the torrid zone, there the winds are more changeable and uncertain.

In ſhort, whatever diſturbs the equilibrium of the atmoſphere, viz. the equal denſity or quantity of air at equal diſtances from the ſurface of the earth; whatever accumulates the air in one place, and diminiſhes it in other places, muſt occaſion a wind both in diſturbing and in reſtoring that equilibrium*.

Thoſe general obſervations ſeem to agree tolerably well with the following facts, which have been aſcertained by the concurring teſtimony of ſkilful ſeamen, and other obſervers.

1. Between the limits of 30°. north and 30°. ſouth latitude, there is a conſtant, or almoſt conſtant, eaſterly wind, blowing, but not violently, at all times of the year, in the Atlantic and Pacific oceans. This is called the *trade wind.*

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* Mr. Briſſon is of opinion that electricity is the principal and more general cauſe which produces winds: "*j'amerois mieux,*" he ſays, "*donner pour cauſe priemière* " *et generale des vents, l'êlectricitê, qu'on ſait qui regne continuellement dans l'atmoſphere, et a la ſurface de notre* " *globe.*" *Principes de Phyſique,* § 1035.—I am by no means of the ſame opinion.

Towards

Towards the middle of the above-mentioned track of about 60°. viz. about the equator, the wind blows either exactly from the eaſt, or very little diſtant from that point; but on the borders of the above-mentioned ſpace, the wind deviates from that point, viz. near the northern limit the trade-wind blows from between the north and the eaſt, and near the ſouthern limit, it blows from between the ſouth and the eaſt.

The trade-wind ſeems to depend principally upon the rarefaction of the air, which is occaſioned by the heat of the ſun progreſſively from the eaſt towards the weſt. The air which is rarefied, and, of courſe, elevated by the heat of the ſun immediately over it, is condenſed and deſcends, as ſoon as the ſun is gone over another place to the weſt of the former; then the air of the latter place is rarefied, and the condenſed air of the former ruſhes towards it, &c. From the northern and ſouthern parts of the world, the air likewiſe runs to the place which is immediately under the ſun; but thoſe directions, combining with the eaſterly wind, which blows nearer to the equator, form the above-mentioned north-eaſterly and ſouth-eaſterly winds on the borders of the trade-wind.

2. In places that are farther from the equator, the rarefaction which ariſes from the heat of the ſun, and from the attraction of the ſun and moon, is leſs active; and is beſides influenced by a variety of local and accidental circumſtances, ſuch as ex-

tenſive continents, mountains, rains, iſlands, &c. which diſturb, interrupt, or totally change the direction of the wind. Hence, in thoſe latitudes north and ſouth, which are beyond the limits of the trade-wind, or near the coaſts, the winds are very uncertain; nor has any good theory been as yet formed reſpecting them: I ſhall, however, proceed to enumerate the facts which have been aſcertained, and to mention the moſt plauſible elucidations of the cauſes upon which they may depend*.

3. In ſome parts of the Indian ocean there are winds which blow one way during one half of the year, and then blow the contrary way during the other half of the year. Thoſe winds are called *Monſoons*, and are explained in the following manner.

It is ſaid, that as the air which is cool and denſe, will force the warm rarefied air in a continual ſtream upwards, there it muſt ſpread itſelf to preſerve the equilibrium. Therefore the upper courſe or current of air muſt be contrary to the under current; for the upper air muſt move from thoſe parts where the greateſt heat is; and ſo, by a kind of circulation, the N.E. trade-wind below will be attended with a S.W. above; and a S.E. below, with a N.W. above.

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* Thoſe particulars have been collected principally by Mr. Robertſon. See his Elements of Navigation, B. VI. Sect. VI.

4. In the Atlantic ocean, near the coaſts of Africa, at about 300 miles from the ſhore, between the north latitudes of 10°. and 28°. ſeamen conſtantly meet with a freſh gale of N.E. wind.

5. Acroſs the Atlantic ocean, on the American ſide of the Caribbee iſlands, it has been obſerved, that the above-mentioned N. E. wind becomes eaſterly, or ſeldom blows more than a point from the eaſt on either ſide of it.

6. Theſe trade winds on the American ſide are often extended as far as the 32^d^ degree of N. latitude, which is about 4° farther than their extenſion on the African ſide. Alſo, on the ſouth-ſide of the equator the trade winds extend 3°, or 4° farther towards the coaſt of Braſil on the American ſide, than they do near the Cape of Good Hope, or African ſide.

7. Between the latitudes of 4°. N. and 4°. S. the wind always blows between the ſouth and eaſt. On the African ſide the winds are neareſt to the ſouth; and on the American ſide, neareſt to the eaſt. In theſe ſeas Dr. Halley obſerved, that when the wind was eaſtward, the weather was gloomy, dark, and rainy, with hard gales of wind; but when the wind turned to the ſouthward, the weather generally became ſerene, with gentle breezes approaching to a calm. Theſe winds are ſomewhat changed by the ſeaſons of the year; for when the ſun is far northward, the Braſil S.E. wind gets to the ſouth, and the N.E. wind to the E.; and when

when the ſun is far ſouth, the S. E. wind gets to the E. and the N.E. wind on this ſide of the equator goes more towards the north.

8. Along the coaſt of Guinea, from Sierra Leon to the iſland of St. Thomas (under the equator) which is above 1500 miles, the ſoutherly and ſouth-weſt winds blow perpetually. It is ſuppoſed that the S.E. trade-wind, having paſſed the equator, and approaching the guinea coaſt within 240 or 300 miles, inclines towards the ſhore, and becomes S., then S.E., and gradually, as it comes near the land, it inclines to ſouth, S.S.W. and cloſe to the land it is S.W. and ſometimes W.S.W.—This tract is ſubject to frequent calms, and to ſudden guſts of wind called *tornadoes*, which blow from all points of the horizon.

The weſterly wind on the coaſt of Guinea is probably owing to the nature and ſituation of the land, which being greatly heated by the ſun, rarefies the air exceedingly; hence the cooler and heavier air from over the ſea will keep ruſhing in to reſtore the equilibrium.

9. Between the latitudes of 4° and 10° north, and between the longitudes of Cape Verd, and the eaſtermoſt of the Cape Verd Iſles, there is a tract of ſea, which ſeems to be condemned to perpetual calms, attended with terrible thunder and lightnings, and ſuch frequent rains, that this part of the ſea is called *the Rains*. It is ſaid that ſhips have ſome-

times

times been detained whole months in ſailing through theſe ſix degrees.

The cauſe of this ſeems to be, that the weſterly winds ſetting in on this coaſt, and meeting the general eaſterly wind in this tract, balance each other, and cauſe the calms; and the vapour carried thither by the hotteſt wind, meeting the cooleſt, is condenſed, and occaſions the very frequent rains.

10. Between the ſouthern latitudes of 10°. and 30°. in the Indian ocean, the general trade-wind about the S.E. by S. is found to blow all the year long in the ſame manner as in the like latitude in the Ethiopic ocean: and during the ſix months from May to December, theſe winds reach to within two degrees of the equator; but during the other ſix months, from November to June, a N.W. wind blows in the tract lying between the latitudes of 3°. and 10°. ſouth, in the meridian of the north end of Madagaſcar; and between the latitudes of 2°. and 12°. ſouth, near the longitude of Sumatra and Java.

11. In the tract between Sumatra and the African coaſt, and from 3° of ſouth latitude quite northward to the Aſiaſtic coaſts, including the Arabian ſea and the gulf of Bengal, the Monſoons blow from September to April on the N.E. and from March to October, on the S.W. In the former half-year the wind is more ſteady and gentle, and the weather clearer than in the latter half-year. Alſo

Alſo the wind is ſtronger and ſteadier in the Arabian ſea than in the gulf of Bengal.

12. Between the iſland of Madagaſcar and the coaſt of Africa, and thence northward as far as the equator, there is a tract, in which, from April to October, there is a conſtant freſh S. S. W. wind, which to the northward changes into the W. S. W. wind, blowing at the ſame time in the Arabian ſea.

13. To the eaſtward of Sumatra and Malacca on the north ſide of the equator, and along the coaſts of Gambodia and China, quite through the Philippines as far as Japan, the Monſoons blow northerly and ſoutherly; the northern ſetting in about October or November, and the ſouthern about May. Theſe winds are not quite ſo certain as thoſe in the Arabian ſea.

14. Between Sumatra and Java to the weſt, and New Guinea to the eaſt, the ſame northerly and ſoutherly winds are obſerved; but the firſt half-year Monſoon inclines to the N. W. and the latter to the S. E.—Theſe winds begin a month or ſix weeks after thoſe in the Chineſe ſeas ſet in, and are quite as variable.

15. Theſe contrary winds do not ſhift from one point to its oppoſite all at once. In ſome places the time of the change is attended with calms, in others with variable winds. And it often happens on the ſhores of Coromandel and China, towards the end of the Monſoons, that there are moſt violent ſtorms,

greatly reſembling the hurricanes in the Weſt Indies, when the wind is ſo vaſtly ſtrong, that hardly any thing can reſiſt its force.

16. The irregularities of the wind in countries which are farther from the equator than thoſe which have been mentioned above, or nearer to the poles of the earth, are ſo great that no particular period has as yet been diſcovered, excepting that in particular places certain winds are more likely to blow than others. Thus at Liverpool the winds are ſaid to be weſterly for near two thirds of the year; in the ſouthern part of Italy a S. E. wind (called the *ſchirocco*) blows more frequently than any other wind, &c.

17. The temperature of a country with reſpect to heat or cold, is increaſed or diminiſhed by winds, according as they come from a hotter or colder part of the world. The north and north-eaſterly winds, in this country and all the weſtern parts of Europe, are reckoned cold and drying winds. They are cold becauſe they come from the frozen region of the north pole, or over a great tract of cold land. Their drying quality is derived from their coming principally over land, and from a well known property of the air, namely, that warm air can diſſolve, and keep diſſolved, a greater quantity of water than colder air: hence the air which comes from colder regions being heated over warmer countries, becomes a better ſolvent of moiſture, and dries up with greater energy the moiſt

moiſt bodies it comes in contact with; and, on the other hand, warm air coming into a colder region depoſits a quantity of the water it kept in ſolution, and occaſions miſts, fogs, clouds, rains, &c. "In "ſhort," *ſays Col. Roy*, "the winds ſeem to be "drier, denſer, and colder, in proportion to the "extent of land they paſs over from the poles to"wards the equator; but they appear to be more "moiſt, warm, and light, in proportion to the ex"tent of ocean they paſs over from the equator "towards the poles. Hence the humidity, warmth, "and lightneſs, of the Atlantic winds to the inha"bitants of Europe. On the eaſt coaſts of North "America the ſeverity of the N.W. wind is uni"verſally remarked; and there can ſcarcely be a "doubt, that the inhabitants of California, and other "parts on the weſt ſide of that great continent, "will, like thoſe on the weſt of Europe, feel the "ſtrong effects of a N.E. wind."

18. In warm countries ſometimes the winds, which blow over a great tract of highly heated land, become ſo very drying, ſcorching and ſuffocating, as to produce dreadful effects. Theſe winds under the name of *Solanos*, are often felt in the deſerts of Arabia, in the neighbourhood of the Perſian gulph, in the interior of Africa, and in ſome other places *. There are likewiſe in India, part

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* See the Abbé Richard's Nat. Hiſt. of the Air and Meteors.

of China, part of Africa, and elſewhere, other winds, which depoſit ſo much warm moiſture as to ſoften, and actually to diſſolve glue, ſalts, and almoſt every article which is ſoluble in water.

19. It is impoſſible to give any adequate account of irregular winds, eſpecially of thoſe ſudden and violent guſts as come on at very irregular periods, and generally continue for a ſhort time. They ſometimes ſpread over an extenſive tract of country, and at other times are confined within a remarkably narrow ſpace. Their cauſes are by no means rightly underſtood, though they have been vaguely attributed to peculiar rarefactions, to the combined attractions of the ſun and moon, to earthquakes, to electricity, &c. They are called in general *hurricanes*, or they are the principal phenomenon of a hurricane, that is, of a violent ſtorm.

Almoſt every one of thoſe violent winds is attended with particular phenomena, ſuch as droughts, or heavy rains, or hail, or ſnow, or thunder and lightning, or ſeveral of thoſe phenomena at once. They frequently ſhift ſuddenly from one quarter of the horizon to another, and then come again to the former point. In this caſe they are called *tornadoes*.

Several years ago ſome general characters or prognoſtics of hurricanes were collected by Capt. Langford, which ſeem not to have been materially contradicted by ſubſequent obſervations. See his Paper in the Philoſophical Tranſactions Abridged, vol.

vol. II. p. 105, from which I have tranſcribed the following five paragraphs.

" All hurricanes come either on the day of the " full, change, or quarter of the moon."

" If it will come on the full-moon, you being in " the change, then obſerve thoſe ſigns."

" That day you will ſee the ſkies very turbu- " lent, the ſun more red than at other times, a " great calm, and the hills clear of clouds, or " fogs, &c."

" It is to be obſerved, that all hurricanes begin " from the north to the weſtward, and on thoſe " points that the eaſterly wind doth moſt violently " blow, doth the hurricane blow moſt fiercely " againſt it; for from the N. N. E. to the E. S. E. " the eaſterly wind bloweth freſheſt; ſo doth the " W. N. W. to the S. S. W. in the hurricane blow " moſt violent; and when it comes back to the " S. E. which is the common courſe of the trade- " wind, then it ceaſeth of its violence, and ſo " breaks up."

" In a tornado, the winds come on ſeveral " points. But before it comes it calms the con- " ſtant eaſterly winds; and when they are paſt, the " eaſterly wind gathers force again, and the weather " clears up fair."

Thoſe obſervations were intended for places within, or not far from the torrid zone, and principally for the Weſt-India iſlands, which are frequently viſited by hurricanes.

20. When the guſts of wind come from different quarters at the ſame time, and meet in a certain place, there the air acquires a circular, or rotatory, or ſcrew-like motion, either aſcending or deſcending, as it were, round an axis, and this axis ſometimes is ſtationary, and at other times moves on in a particular direction. This phenomenon, which is called a *whirlwind*, gives a whirling motion to duſt, ſand, water, part of a cloud, and ſometimes even to bodies of great weight and bulk; carrying them either upwards or downwards, and laſtly ſcatters them about in different directions.

The *water ſpout* has been attributed principally, if not entirely, to the meeting of different winds. In that caſe the air in its rotation acquires a centrifugal motion (ſee p. 138 of part I.); whence it endeavours to recede from the axis of the whirl, in conſequence of which a vacuum, or, at leaſt, a conſiderable rarefaction of air, takes place about the axis, and, when the whirl takes place at ſea, or upon water, the water riſes into that rarefied place; for the ſame reaſon which cauſes it to aſcend into the exhauſted tube (ſee page 205 of this part), and forms the water-ſpout or pillar of water in the air: yet the various appearances of water ſpouts do not ſeem to be quite reconcilable to the above mentioned theory.—Some ingenious perſons have conſidered the water ſpout as an electrical phenomenon; having obſerved, that thunder clouds and lightnings

lightnings have been frequently ſeen about the places where water ſpouts appear, and likewiſe that by means of artificial electricity, a water ſpout may in ſome meaſure be imitated. But it muſt be obſerved, that the lightning and other electrical phenomena appear to be rather the neceſſary conſequence than the cauſe, of the water ſpout; it being well known that electricity is produced whenever water is reduced into vapour, or vapour is condenſed into water. We ſhall, however, examine this particular in another part of theſe elements.

The following are the moſt remarkable facts relative to water ſpouts.

Two, or three, or more, water ſpouts are frequently ſeen within the ſpace of a few miles, and they are moſtly ſeen at ſea.

Their ſize is various, not exceeding, however, a few feet in diameter; and the ſame water ſpout ſometimes increaſes and decreaſes alternately; it alſo appears, diſappears, and reappears, in the ſame place.

The water ſpout ſometimes proceeds a little way from a cloud, or a little way from the ſea; and often thoſe two ſhort and oppoſite ſpouts are not only directed towards each other, but they are extended and meet each other.

When it proceeds from the ſea, the water about the place appears to be much agitated, and riſes a ſhort way in the form of a jet or ſpray, or ſteam, in the middle of which a thick, well defined, and generally opaque, body of water riſes, and proceeds to a conſiderable height into the atmoſphere, where it is diſſipated into a vapour, or it ſeems to form a cloud.

When it proceeds from a cloud, the clouds about the ſpot frequently appear much agitated, and an agitation of the water immediately under the ſpot is generally ſeen at the ſame time.

The water ſpout is frequently ſeen to have a ſpiral or ſcrew-like motion, and ſometimes is attended with conſiderable noiſe.

Some of them ſtand in a perpendicular direction, others are inclined, and ſome water ſpouts form a curve, or even an angle.

The water ſpouts generally break about their middle, and the falling waters occaſion great damage, either to ſhips that have the misfortune of being under them, or to the adjoining land; for ſuch ſpouts are ſometimes formed on a lake, or river, or on the ſea cloſe to the land.

Sometimes the water ſpouts are ſeen where there is no appearance of whirlwind, or where the wind (at leaſt to a ſpectator at ſome diſtance) appears to blow regularly one way.

The oblique ſpouts almoſt always point from the wind; for inſtance, when the wind is N.E. the ſpout will point to the S. W. fig. 20. of

Plate XIII. repreſents a water ſpout of the moſt complete form*.

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* Several particular accounts of water ſpouts may be ſeen in various volumes of the Philoſophical Tranſactions, eſpecially in the 4th volume of Jones's Abridgment. Alſo in Franklin's Miſcellaneous Papers; in almoſt all the accounts of voyages; and in moſt works upon Electricity.

CHAPTER XI.

OF SOUND, OR OF ACOUSTICS.

THE ſenſation, which we perceive through the organ of hearing, is called *ſound*; ſuch as the ſound of a human voice, or of the voices of other animals; as the ſound of a bell, or of the ſtroke of a hammer, of the wind amongſt trees, or of falling water, of an organ, &c.

The ſcience which treats of ſound in general is called *acouſtics* (from the Greek verb for *hearing)* or *phonics* (from the Greek word which means a voice or ſound). And moſt of the other terms which are uſed in treating of ſound, are derived from the above-mentioned words; ſuch as *diacouſtics*, viz. of refracted ſound; *catacouſtics*, viz. of reflected ſound, or of the *echo*; *otacouſtics*, viz. of the means of improving the ſenſe of hearing, as by means of the hearing trumpet, &c.

The body which produces the ſound is called the *ſonorous body*, or *ſounding body*; and whilſt ſounding, the ſonorous body is evidently, and unqueſtionably, in a ſtate of vibration.

Air is the only ſubſtance which, in common, ſeems to exiſt between ſonorous bodies and our ears; and it has been obſerved that, *cæteris paribus*, the ſound of the very ſame ſonorous body, ſuch as as a bell, a drum, &c. is louder or more powerful, and may be heard farther, where the air is denſer, as in vallies, than where the air is leſs denſe, as on the tops of high mountains. Therefore we are led to conclude that air is the vehicle of ſound, viz. that the ſonorous body communicates a vibratory motion to the ſurrounding air, which motion is gradually communicated from the air next to the ſounding body, to that which is more diſtant from it, ſomewhat like the waves upon the ſurface of water; until that vibratory motion is communicated to the ſenſible part of the ear. But ſound is likewiſe conveyed by other bodies, both ſolid and fluid; as will be ſhewn in the ſequel.

Infinite is the variety of ſounds; for a manifeſt difference is to be perceived between the voices of any two human beings, or between the voices of other animals; and perſons who have accuſtomed their ears to nice diſcriminations, can diſtinguiſh a difference between the ſounds of very ſimilar muſical inſtruments, viz. ſuch as are conſtructed, tuned and ſtruck, to all appearance, perfectly alike.

The variety of ſounds ariſes from three cauſes principally, viz. 1ſt, from the greater or leſs frequency of the vibrations of the ſonorous bodies; 2dly, from the quantity, force, or momentum of the vibrating particles which ſtrike the ear; and 3dly, from the greater or leſs ſimplicity of the ſounds.

Hence are derived the *height*, the *ſtrength*, and the *quality* of a ſound.

1. If you ſtrike the ſtring of a muſical inſtrument, then ſtop that ſtring in the middle, and ſtrike one half of it only, or ſtop any part of it, and ſtrike the other part, the ſhort part will perform quicker vibrations, or what is called a higher tone, than the whole ſtring; ſo that the frequency of the vibrations produces *high* or *low*, *acute* or *grave*, *ſharp* or *flat*, ſounds; for the more frequent the vibrations are, the higher, or more acute, or ſharper, is the ſound ſaid to be, and *vice verſa*.

2. The ſtrength of ſound ariſes from the ſpace through which the vibrating parts move, or from the length of the vibrations; it is alſo owing to reflection. The vibratory motion of a ſounding body is communicated ſpherically all round the body, and of courſe, like other emanations from a centre, is gradually diminiſhed in intenſity, according to the diſtance (ſee page 62. Part I.) *.

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* The decay of ſound, or the diminution of its intenſity, has been ſuppoſed by D. Bernoulli, De la Grange, and others, to be nearly in the direct ratio of the diſtances. But other ingenious perſons have ſuppoſed it to be nearly as the ſquares of the diſtances. Their reaſonings and calculations are eſtabliſhed on different principles; but all the particulars which ſhould be taken notice of in this calculation, are by no means known; nor do we know of any practical method of meaſuring the intenſity of ſound.

But if that communication be prevented on certain ſides, and be permitted to take place on a particular ſide only; or if the vibrations which are communicated by the ſame ſonorous body to different bodies, be reflected from the latter to a particular place; the ſound will be heard in that place much louder than otherwiſe. Hence ariſes the effect of the *ſpeaking trumpet*, or *ſtentorophonic tube* *; hence

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* In a ſpeaking trumpet the ſound in one direction is ſuppoſed to be increaſed, not ſo much by its being prevented to ſpread all round, as by the reflection from the ſides of the trumpet. But as the real action of the inſtrument, or the true motion of the air through it, is not clearly underſtood; different perſons, according to their particular conceptions of the caſe, have recommended peculiar ſhapes for the conſtruction of ſuch trumpets; ſome having recommended a conical ſhape, others that which is formed by the rotation of certain curves round their axes; others again have recommended an enlargement or two of the cavity in the length of the trumpet, &c. That which has been more commonly recommended as the beſt figure for ſuch trumpets, is generated by the rotation of a parabola about a line parallel to the axis.

A ſpeaking trumpet of the ſhape moſtly uſed by navigators, is repreſented at fig. 15. Plate XIII. It is an hallow inſtrument of copper or of tinned iron-plates. It is open at both ends; and the narrow end, A, is ſhaped ſo as to go round the ſpeaker's mouth, and to leave the lips at liberty within it. The edge of this narrow end is generally covered with leather or cloth, in order that it may more effectually hence the effect of what are called *whiſpering galleries*, or *whiſpering domes*; hence the ſound of a bell, or the report of a piſtol in a room, produces a much ſtronger effect upon our ears than in the open air, &c.

3. A ſounding body vibrates in more directions than one; for inſtance, if a body of irregular ſhape or ſize be ſtruck, the thin parts of it will perform their vibrations in different times from thoſe in

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fectually prevent the paſſage of any air between the trumpet and the face of the ſpeaker. When a perſon applies his mouth to the narrow end, and, directing the tube to a particular place, ſpeaks in it; the words may be heard much farther and much louder in the direction of the trumpet, by perſons who are before it, than they would without the trumpet. A perſon who is not in the direction of the trumpet will hear the ſound of it both weaker and leſs diſtinct, in proportion as he is more or leſs diſtant from the direction of the ſound; which is the direction ſtraight before the trumpet.

The words which are ſpoken through a ſpeaking trumpet may be heard much farther and louder, but not ſo diſtinctly, as without the trumpet.

A ſpeaking trumpet has alſo been applied to the mouth of a gun or piſtol, by which means the exploſion has been rendered audible at a vaſt diſtance.—Such contrivances may be uſed as ſignals in certain caſes.

See the deſcription of ſome particular ſhapes of ſpeaking trumpets in the Philoſophical Tranſactions, N° 141, or Lowthorp's Abridgment, vol. I. page 505.

which the thicker parts perform their vibrations; hence ariſe different ſounds from the ſame body at the ſame time; and thoſe different ſounds are greater in number and quality, according to the irregularities of the ſounding body. The more uniform the ſounding body is in ſhape and quality, the ſimpler, more uniform, and more pleaſing its ſound is; but probably there is no ſounding body in nature, which emits a ſingle ſound. However, when the ſounding body emits one predominant ſound, and the concomitant ſounds are barely diſtinguiſhed, then that predominant ſound may be conſidered as a *ſimple ſound.*

From the combination of the above-mentioned three cauſes, the various ſounds derive their denominations of *high*, *low*, *weak*, *harſh*, *clear*, *rough*, *ſmooth*, *pleaſant*, *unpleaſant*, *confuſed*, &c.

The human voice is capable of expreſſing the greateſt variety of ſounds.

The vibratory motion of a ſounding body will continue for a longer or ſhorter time after the ſtroke which cauſes it to vibrate, according as that body is more or leſs elaſtic; as it is thicker or thinner, &c.

This vibratory motion, eſpecially when the ſounding bodies are large and powerful, as a large bell, a large ſtring of a muſical inſtrument, and ſuch like, is generally apparent to the naked eye; but it may be rendered ſtill more manifeſt by bringing a finger, or other ſolid, very near their ſurfaces.

When a ſtring of uniform ſhape and quality is ſtretched between, and is fixed to, two ſteady pins, as A, B, fig. 16, of Plate XIII. if it be drawn out of its natural, or quieſcent, poſition AB, into the ſituation ACB, and if then it be let go, it will, in conſequence of its elaſticity, not only come back to its poſition AB; but it will go beyond it, to the ſituation ADB, which is nearly as far from AB, as ACB was on the other ſide, and all this motion one way is called one vibration; after this, the ſtring will go again nearly as far as C, making a ſecond vibration; then nearly as far as D, making a third vibration, and ſo on; diminiſhing the extent of its vibrations gradually, until it ſettles in its original poſition AB.

It ſeems natural that the air, which is contiguous to the ſounding body, muſt receive the like vibratory motion, viz. it muſt be cauſed to perform vibrations of equal duration with thoſe of the ſounding body; and thoſe vibrations, being ſpread ſucceſſively through the air, in their courſe, reach our ears, and communicate to them the like vibrations, which excite in us the ſenſation of a particular ſound.

The air communicates the above-mentioned vibrations not only to the organs of hearing; but likewiſe to other ſolids in certain circumſtances, viz. to ſuch ſolids as, if ſtruck, would emit a ſound which is either exactly like, or bears ſome analogy to, that of the original ſounding body. Thus let the ſtring of a violin be tuned exactly like a ſimilar ſtring of another violin; ſo that if either of them be ſtruck, the ſame ſound may be heard. Place a little bit of paper upon the ſtring of one of the violins, about the middle of it, and place that inſtrument upon a table; let the other violin be held near it, for inſtance, within a foot or two, and in that ſituation ſtrike the above-mentioned ſtring of the latter violin. It will be found that whilſt this is ſounding, the correſponding ſtring of the other violin upon the table, will evidently vibrate, as is manifeſted by the bit of paper upon it.

In ſhort, it has been generally obſerved, that if of two ſtrings, or of two other ſonorous bodies, which are capable of performing their vibrations in equal times, one only be cauſed to ſound, the other ſtring or other ſonorous body will alſo be found to vibrate, provided it be not too far from the firſt mentioned ſonorous body.

The ſame thing, though not in an equal degree, will take place if one of the ſonorous bodies be capable of performing two, or three, or four complete vibrations, whilſt the other is capable of performing one vibration only, and either of them is cauſed to ſound.

If one of the ſtrings which is put in motion, performs three vibrations, whilſt another ſtring, which is to be ſet a vibrating by the ſound of the firſt, can perform only one vibration with its whole length; then this laſt ſtring will divide itſelf into three vibrating

brating parts, and there will be two points at reſt, as may be ſeen by placing bits of paper or other light bodies upon different parts of the latter ſtring.

This ſhews that the vibrations of the ſounding body are communicated to the air, and by the air to the other ſonorous body. It ſhews likewiſe, that the vibrations of the air muſt be performed in the ſame time as thoſe of the ſounding body*.

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* A ſtring, or a body capable of being put in a ſtate of vibration, as a pendulum at reſt, may be cauſed to vibrate by the repeated application of the leaſt impulſe, provided thoſe impulſes be repeated at the expiration of ſuch portions of time as the pendulum, or other body, would perform every two of its vibrations; for inſtance, if a pendulum, when put in motion, would perform each vibration in one ſecond, and of courſe it would come to the ſame ſide every other ſecond; then if, when ſuch a pendulum is at reſt, you give it an impulſe ever ſo little (even a puff of air from your mouth) at the end of every two ſeconds; the pendulum will ſoon be ſeen to vibrate. The reaſon of which is, that from the law of colliſion, (ſee page 42 of Plate I.) ſince every impulſe muſt produce a proportionate effect, the firſt impulſe muſt cauſe the pendulum to move a little out of the perpendicular, or to perform a ſhort, and perhaps an inviſible, vibration; and if no other impulſe were given, the pendulum would by itſelf (ſee page 174 of P. I.) perform another vibration ſhorter than the firſt, then another ſtill ſhorter, and ſo on; but by giving it the ſecond impulſe at the end of the proper time, the effect of that impulſe, conſpiring with the natural motion of the pendulum, will enable

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The ſurface of water is agitated a little by the ſound of a large bell, or the report of canon. Windows, wainſcots, &c. are frequently cauſed to vibrate by the ſound of organs, and other large inſtruments.

The communication of the vibrations to the air is uſually explained in the following manner.—Let the ſonorous body be a ſtring faſtened to, and ſtretched between, two fixed pins; (for whatever is ſaid with reſpect to the vibrations of the ſtring,

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it to perform a longer vibration than it could perform without it. By the ſame way of reaſoning it will appear that the third impulſe will increaſe the length of the vibrations ſtill more, and ſo on.

If the impulſe be repeated at the end of every 4, or every 6, &c. vibrations; the vibration of the pendulum will alſo be increaſed, and will at laſt become viſible, but not ſo effectually as by the repetition of the impulſe at every other vibration; which is ſo evident as not to require any farther illuſtration.

If the impulſes be repeated not at the proper intervals of time, then their action, inſtead of conſpiring with the motion of the pendulum, will check the little motion which was communicated to it by the firſt impulſe, and of courſe the vibration of the pendulum cannot be rendered viſible.

Therefore, whenever we find that a certain body is cauſed to vibrate by the reiteration of a certain weak impulſe, we may conclude that ſuch impulſe has been repeated at ſuch intervals of time as the body is capable of performing two, or four, &c. of its vibrations.

may be applied to the vibration of other ſounding bodies) and *a*, *b*, *c*, *d*, &c. be a row of aërial particles on one ſide, and in the direction of the vibrations of the ſtring. When this ſtring is cauſed to vibrate, the firſt vibration will drive the particle *a*, towards *b*, and of courſe *b* muſt impel *c* towards *d*, &c. but whilſt the motion is thus communicated from one particle to the next, the ſtring goes back towards the axis, or performs its ſecond vibration. This removes the preſſure from *a*, *b*, &c. and beſides the ſtring, by its quick motion, occaſions a rarefaction at the place where a little before it had cauſed a condenſation, in conſequence of which the particles *a* and *b* will recede a little way from each other, and this expanſion will gradually proceed through the adjoining particles; then again another condenſation on that ſide takes place, &c. Thus the ſucceſſive waves or ſhells of condenſed and rarefied air follow each other.

The beſt way of explaining the croſſing of various ſounds, or of the vibrations which ariſe from ſeveral ſounds at the ſame time, may perhaps be by ſuppoſing, that the air partakes of all the various vibrations; ſomewhat like the croſſing of the waves of water (ſee p. 158); viz. that each ſhell of condenſed and rarefied air, which is the conſequence of one ſound, is itſelf alternately condenſed and rarefied in another direction, in conſequence of a ſecond ſound, &c.

The vibration of the air cannot be ocularly perceived,

ceived, except in an imperfect manner by the very ſmall motion of the particles of duſt, ſmoke, &c. which are ſeen to float in the air in certain lights, and which are made to vibrate in a ſmall degree by the powerful ſound of a large ſonorous body.

But the explanation of the vibration of a ſtretched ſtring, which we have given above in a ſimple manner for the ſake of perſpicuity, is far from being accurate and complete. In the firſt place it is eaſy to perceive that the ſtring, AB, fig. 16. Plate XIII. muſt be longer when it ſtands in the ſituation ACB, or ADB, than when it ſtands ſtraight between A and B; therefore it appears, that beſides the lateral, there is alſo a longitudinal, vibration, which is capable of producing another ſound, though not ſo powerful as that of the lateral vibration.

Secondly, the ſtrings of muſical inſtruments in their vibrations, eſpecially at firſt, form curves ſomewhat different from each other, according to the different methods by which they are cauſed to vibrate, viz. whether they be ſtruck in the middle, or cloſe to one end; whether by the application of a finger, or a quil, or a bow, &c.*

Thirdly,

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* The ſhapes which the ſame ſtring aſſumes in its vibrations, after having been ſtruck by different methods, may, in great meaſure, be perceived. "Take," ſays *Dr. Young*, "one of the loweſt ſtrings of a ſquare piano forte, round "which

Thirdly, the ſtring ſometimes ſeems to divide itſelf into parts, viz. ſome parts of the ſtring perform vibrations peculiar to their lengths at the ſame time that they partake of the general vibrations.

And, fourthly, a ſtring ſeldom continues long to vibrate in one and the ſame plane; but the plane of its vibrations moves in different directions, which are far from being regular. This deviation of the plane of vibration from its original ſituation, may probably be owing to the obliquity of the impulſe, or to the inequalities in the figure of the ſtring, or to the reſiſtance of the air, &c. This movement of the plane of vibration may be diſcerned by viewing a ſounding ſtring in the direction of its length.

If the movements of a ſtretched ſtring be ſo complicated and uncertain, one may eaſily conceive the difficulty of comprehending, or of inveſtigating,

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" which a fine ſilvered wire is wound in a ſpiral form; con-
" tract the light of a window; ſo that, when the eye is
" placed in a proper poſition, the image of the light may
" appear ſmall, bright, and well defined on each of the con-
" volutions of the wire. Let the chord be now made to
" vibrate, and the luminous point will delineate its path,
" like a burning coal whirled round, and will preſent to the
" eye a line of light, which, by the aſſiſtance of a microſcope,
" may be very accurately obſerved." Phil. Tranſ. for 1800.
page 135.

the movements of other ſounding bodies, the greateſt part of which are vaſtly more irregular in ſhape and quality than the ſtretched ſtring.

The vibrations of the air, which are produced by the above-mentioned movements of the ſame ſounding body, muſt evidently be very complicated and uncertain. Beſides, even in the ſimpleſt mode of vibration, as that of the ſtring; it is evident that the collapſing of the air behind it muſt occaſion another ſort of vibration, beſides that which is produced on the fore part of the ſtring. In ſhort, it muſt be confeſſed, that the real motion of the air, or its various movements, in its conveyance of ſound, are far from being rightly underſtood.

Moſt ſonorous bodies not only perform different vibrations at the ſame time, but they may be cauſed to perform certain vibrations and not others, or they may be cauſed to vibrate at pleaſure in certain directions more powerfully than in other directions; and that by the different manner of holding or ſtriking them. Thus, if a glaſs, partially filled with water, be ſtruck on the ſide, it will emit one ſound, and if, inſtead of that, you rub your wet finger over the edge of it, you will perceive a different ſound.

Moſt oblong and elaſtic bodies may be cauſed to vibrate longitudinally by means of proper friction in the direction of their length. They may be rubbed with the finger, or with any ſoft ſubſtance over which ſome pounded roſin is ſpread. The beſt way of rubbing glaſs rods, is by means of a wet rag beſtrewed with fine ſand*.

The ſounds which ariſe from the longitudinal vibrations of ſonorous bodies, are conſiderably higher than thoſe which are produced by the lateral vibrations of the ſame bodies. The former agree with the latter in this, viz. that they are higher or lower inverſely as the lengths of the ſonorous body; but otherwiſe a very ſtriking difference is to be remarked between the production of the former and that of the latter; namely, that the production of the latter depends upon the length, weight, and tenſion of the ſtring or other ſonorous body: whereas the former depend more upon the quality or nature of the ſonorous body, than upon its thickneſs and weight. "I have examined," ſays *Dr. Chladni*, "every ſubſtance "which I could obtain in a ſufficiently long rod-"like form, in regard to longitudinal vibration; "for example, many kinds of wood and metal, "alſo glaſs, whalebone, &c. The ſpecific gravity

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* Dr. Chladni of Wittemberg, who has made a very great number of experiments on the longitudinal vibrations of elaſtic bodies, lately contrived a muſical inſtrument, which he calls the *euphon*, and which conſiſts of glaſs rods diſpoſed in a proper frame, which expreſs their ſounds by being rubbed longitudinally. A ſhort account of this inſtrument may be ſeen in the Phil. Mag. vol. II. p. 391.

"makes no difference; for fir-wood, glaſs, and "iron, give almoſt the ſame tone, as alſo braſs, "oak, and the ſhanks of tobacco-pipes made of "clay*."

Different bodies are more or leſs ſonorous; but that property does not ſeem to be entirely dependent, either upon their ſpecific gravity, or their tenacity, or even their elaſticity. Copper ſeems to be the moſt ſonorous of the ſimple metals, then comes ſilver, then iron, tin, platina, gold, and, laſtly, lead, which ſeems to be the leaſt ſonorous metallic ſubſtance.

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* Dr. Chladni has rendered, in great meaſure, apparent the different ſorts of vibration, or rather the different parts of flat ſonorous bodies, which are cauſed to vibrate by peculiar managements.—His method is briefly as follows:

If you take a pane of glaſs, or a thin metallic plate, or a piece of board, &c. and ſtrew very light bodies, ſuch as fine ſand, over it. Then, holding it horizontally between your finger and thumb, you rub a violin bow acroſs the edge of the plate; you will find that part of the plate is thereby cauſed to vibrate, as will be ſhewn by the motion of the ſand; and by continuing the friction of the bow, you will perceive that the ſand will be gradually removed from the vibrating parts, to thoſe parts which do not vibrate.

By holding the plate in different places, and by applying two or more fingers to it, and then rubbing the bow acroſs one part or another of the edge, the ſand may be cauſed to aſſume different forms (called *vibration figures*) ſuch as a circle, an ellipſis, a quadrangle, &c. See the Phil. Mag. vol. III. p. 389.

The communication of the vibrations from the vibrating part of a ſtretched ſtring to ſome other part of it, which, at firſt ſight, might be ſuppoſed to be at reſt, is likewiſe attended with remarkable phenomena*.

If you divide a ſtring, as AD, fig. 17. Plate XIII. into three equal parts AB, BC, CD, by placing dots at C and B; place a bridge, like a violin bridge at B, alſo place light bodies, ſuch as ſmall bits of paper, at C, and at other places of the part BD; then draw a violin bow over the part AB; you will find that all the bits of paper will be thrown off from the part BD, excepting the one at C; ſhewing that the point C remains at reſt, whilſt the remainder of the ſtring is vibrating.—This point, and all other points whereon, in ſuch experiments, the bits of paper remain at reſt, as alſo the point B, where the bridge is ſituated, are called *vibration nodes.*

Divide the ſtring AB (fig. 18. Plate XIII.) by the points C, D, E, F, into five equal parts; intercept, by means of two bridges, the part DE; place ſmall bits of paper upon C and F, as alſo upon other parts of the ſtring; then rub the violin bow acroſs the part DE, and you will find that all the bits of paper will be ſhaken, except thoſe at C and F.

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* See Voigt's Experiments, in Gren's *Journal de Phys.* Vol. II. Part III.

Thus, by a proper diviſion of the ſtring, and by intercepting one or more aliquot parts of it, &c. any moderate number of vibration nodes may be exhibited*. But it muſt be obſerved, that in thoſe experiments, the communication of motion from the ſounding part of the ſtring, to the other, may be effected not ſo much through the ſubſtance of the ſtring, as through the air. See p. 315.

In an organ pipe, and other wind inſtruments, it is not the inſtrument itſelf that principally vibrates; or rather the ſound is produced by the vibration of the column of air within the pipe. In a large organ pipe this vibration of the column of air, which is ſomewhat longer than the pipe, may be felt by applying the open hand to the aperture of the pipe. But the particular manner in which this vibration is performed, is by no means rightly understood.

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* The general rule for finding out the number of vibration nodes, according to any diviſion of the ſtring, is as follows:

Suppoſe the ſtring to be divided into *n* number of parts, and that the portion, which is intercepted by the bridge or bridges, conſiſts of *m* number of ſuch parts; expreſs the ratio of *n* to *m* in the loweſt terms; ſubtract the latter from the former, and the remainder ſhews the number of vibration nodes. Thus, in the firſt example, *n* is equal to 3, *m* is equal to 1, and 1 being ſubtracted from 3, there remains 2; ſo that the vibration nodes are 2, viz. one at C, and the other at D.

underſtood.—The ſound of the ſame pipe may be increaſed or diminiſhed in quantity, or in acuteneſs, by ſupplying the pipe with different quantities of air, and by particular modes of blowing*.

Upon the whole it appears, that, by certain managements, the height of a ſound may be increaſed or diminiſhed; and, by other managements, the ſtrength and quality of the ſound may be altered. Thus expert violin players paſs the bow over the ſtrings ſometimes very cloſe to the bridges of their violins; and, at other times, at a greater diſtance, or nearer to the middle of the ſtrings: by which means, *cæteris paribus*, they actually produce different effects.

It alſo appears that every ſound, even thoſe of the ſimpleſt muſical inſtruments, is accompanied with other inferior, ſecondary, or leſs audible, ſounds; and thoſe ſecondary ſounds are heard more diſtinctly when the ſounding bodies are large or powerful, and when the principal ſound is grave and continuate, than otherwiſe.—Hereafter, in ſpeaking of the ſounds, or of the vibrations, of ſounding bodies, we mean only the vibrations which produce the principal or predominant ſound, unleſs the contrary be mentioned.

We ſhall now ſtate the moſt uſeful facts and obſervations which have been eſtabliſhed and made

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* See Dr. Young's Experiments, Phil. Tranſ. for 1800. p. 121.

by various ingenious perſons, concerning the velocity, intenſity, communication, reflection, and other properties of ſounds in general.

Sound is propagated ſucceſſively from the ſounding body, to the places which are nearer to it, then to thoſe that are farther from it, &c.

A great many long and laborious calculations have been made by divers able philoſophers and mathematicians, for the purpoſe of deducing the velocity of ſound through the air, from the known weight, elaſticity, and other properties of air; but the reſults of ſuch calculations differ conſiderably from each other, as alſo from the reſults of actual experiments, which ſhews either that the calculations have been eſtabliſhed upon defective principles, or that not all the concurring circumſtances have been taken into the account. Therefore, without mentioning any thing farther with reſpect to thoſe calculations, I ſhall immediately ſtate the reſult of authentic and uſeful experiments.

Almoſt every body knows, that when a gun is fired at a conſiderable diſtance from him, he perceives the flaſh a certain time before he hears the report; and the ſame thing is true with reſpect to the ſtroke of an hammer, of an hatchet, with the fall of a ſtone, or, in ſhort, with any viſible action which produces a ſound or ſounds. This time which ſound employs in its motion through

through the common air, has been meaſured by various ingenious perſons. The principal and more general method has been to meaſure (by means of a ſtop watch or a pendulum) the time which elapſes between the appearance of the flaſh, and the hearing of the report of a gun fired at a certain meaſured diſtance from the obſerver; for light travels ſo faſt through the diſtance of 1000, or 2000 miles, that we cannot poſſibly perceive the time; therefore we may conclude that the exploſion of a gun takes place at the very ſame moment in which we perceive the flaſh.

In the firſt place it has been unanimouſly obſerved, that ſound travels at a uniform rate, viz. that it will go as far again in two ſeconds, as it will in one ſecond; that it will go three times as far in three ſeconds, or four times as far in four ſeconds, as it will in one, and ſo on. Therefore, in the above-mentioned manner of performing the experiment, if the diſtance (in feet) between the cannon, and the obſerver, be divided by the number of ſeconds elapſed between the perceptions of the flaſh and of the report, the quotient will ſhew the rate of travelling, or how many feet per ſecond ſound runs through.

This rate has been eſtimated differently by different perſons, whoſe experiments have been performed at different times, in different places, and with inſtruments more or leſs accurate, viz.

By

	Feet per Second.
(*a*) By Sir Iſaac Newton, at the rate of	968
(*b*) By the Hon. Mr. Robarts, at -	1300
(*c*) By the Hon. Mr. Boyle, at - -	1200
(*d*) By Mr. Walker, at - - - -	1338
(*e*) By Merſennus, at - - - -	1474
(*f*) By the Florentine Academicians -	1148
(*g*) By the French Academicians -	1172
(*h*) De Thury, Maraldi, and de la Caille - - - - - - - - - -	1107
(*i*) By Flamſtead, Halley, and Derham, at - - - - - - - -	1142

Dr. Derham, as it appears from the account in the Philoſophical Tranſactions, ſeems to have made the greateſt number of accurate and more diverſified experiments; therefore we may take his concluſion, which coincides with thoſe of Flamſtead and Halley, as the neareſt to the truth, viz. that,

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(*a*) Principia. B. II. Prop. 50.

(*b*) Phil. Tranſ. n. 209.

(*c*) Eſſay on Motion.

(*d*) Phil. Tranſ. n. 247.

(*e*) Baliſtic. Prop. 39.

(*f*) Exp^{ts}. of the Acad. *del Cimento.* p. 141.

(*g*) Du Hamel Hiſt. Acad. Reg.

(*h*) They reckoned it equal to 173 toiſes, which are nearly = 1107 feet Engliſh. See Mem. de l'Acad. for 1738, p. 128, &c.

(*i*) Phil. Tranſ. Jones's Abrid. vol. IV. p. 396.

in

in general, ſound travels uniformly through the atmoſpherical air at the rate of 1142 feet per ſecond, or one mile in little leſs than 5 ſeconds; at leaſt, this reſult cannot differ from the truth by more than 15 or 20 feet*. But it will appear from the following paragraphs, and from the difficulty of meaſuring time to a fraction of a ſecond, that no very great degree of accuracy can be expected in meaſurements of this ſort.

Derham obſerved, that the report of a cannon fired at the diſtance of 13 miles from him, did not ſtrike his ear with a ſingle ſound, but that it was repeated five or ſix times cloſe to each other. "The two firſt cracks," *he ſays*, "were louder "than the third, but the laſt cracks were louder "than any of the reſt. - - - - - And beſides, in "ſome of my ſtations, beſides the multiplied "ſound, I plainly heard a faint echo, which was "reflected by my church, and the houſes adja"cent."

This repetition of the ſound probably originated from the reflection of a ſingle ſound from hills, houſes, or other objects, not much diſtant from the cannon. But it appears from general obſervation, and where no echo can be ſuſpected, that the ſound of a cannon, at the diſtance of 10 or 20 miles, is different from the ſound when near. In

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* According to Mr. Hales, the undulation of water is to the motion of ſound as 1 to 865.

the

the latter caſe the crack is loud and inſtantaneous, of which we cannot appreciate the height. Whereas in the former caſe, viz. at a diſtance, it is a grave ſound, which may be compared to a determinate muſical ſound; and, inſtead of being inſtantaneous, it begins ſoftly, ſwells to its greateſt loudneſs, and then dies away growling.—Nearly the ſame thing may be obſerved with reſpect to a clap of thunder. Other ſounds are likewiſe altered in quality by the diſtance.

Upon the whole, it appears that the velocity of ſound is exactly the ſame, whether the ſound be high or low, ſtrong or feeble, whether it be the ſound of a human voice, or the report of a cannon. But its velocity is ſenſibly altered by winds. If the wind conſpires with the ſound, viz. if it blows in the direction from the ſounding body to the hearer, the ſound will be heard ſooner; and if the wind blows the contrary way, the ſound will be heard later, than according to the rate of 1142 feet per ſecond. In ſhort, the velocity of the wind, in the former caſe, muſt be added to, and in the latter it muſt be ſubtracted from, that of the ſound*. But the

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* The knowledge of this fact will enable us to meaſure, pretty nearly, the velocity of the wind in certain caſes; for if a cannon be fired at a known diſtance from us, the report muſt reach us ſooner when the wind blows from that place to us, and later when it blows the contrary way, than it will in

the velocity of the air in the ſtrongeſt wind is, perhaps, not equal to the twentieth part of the velocity of ſound.

Heat and cold ſeem to make a very ſmall alteration in the velocity of ſound; for ſound appears to travel a little faſter in ſummer then in winter.

Different altitudes of the barometer, as alſo different quantities of moiſture in the air, ſeem to occaſion a ſmall alteration in the velocity of ſound. But it is not in our power to determine what ſhare of the effect is due to each of thoſe cauſes.

Upon the whole it appears, that whatever increaſes the elaſticity of the air, accelerates the motion, as alſo the intenſity of ſound, through it, and *vice verſa*. Or in fluids of a determinate elaſticity, whatever increaſes the denſity, diminiſhes the velocity of ſound through them. Probably the velocities of ſound through ſuch fluids, are as the ſquare roots of the denſities.—Experience ſeems to prove, that at different times of the year (the influence of winds being excluded) the velocity of ſound may be faſter or ſlower, not exceeding 30 feet, than at the above-mentioned mean rate of 1142 feet per ſecond.

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in calm weather; therefore, knowing in what time it ought to reach us in calm weather, the difference between that time and the time obſerved in the above-mentioned caſes of windy weather, is the time which the wind employs in paſſing through that diſtance.

The knowledge of the velocity of ſound through the air, may be applied to a very uſeful purpoſe, viz. to the meaſurement of diſtances, eſpecially when no better method can be uſed with conveniency. Thus we may meaſure the diſtance of a thunder cloud by meaſuring the time which elapſes between the appearance of the flaſh of lightning, and the report of the exploſion or thunder; for if by looking upon a clock or a watch with a ſecond's hand, we find that the time elapſed is one ſecond, we may conclude that the exploſion took place at the diſtance of 1142 feet from us; if the elapſed time be two, or three, or any other number of ſeconds, we may conclude that the diſtance is the product of 1142 multiplied by two, or by three, or by the other number of ſeconds. After the ſame manner by obſerving the flaſh and the report of a gun, or the motion of the hand which moves an hammer, and the perception of the ſound, &c. we may determine, pretty nearly, the diſtance of a ſhip, or of an iſland, or of a workman, &c.

Air is always around us, and therefore is the moſt common medium through which ſounds are tranſmitted: but ſounds may alſo be conveyed by other bodies, both ſolid and fluid, viz. by water, by metals, by wood, by ſtones, by ropes, &c. and in moſt caſes more readily and perfectly than by the air. Probably there is no ſubſtance which is not in ſome meaſure a conductor of ſound; but ſound is much enfeebled by paſſing from one medium to another.

If

If a man ſtops one of his ears with his finger, ſtops the other ear by preſſing it againſt the end of a long ſtick, and a watch be applied to the oppoſite end of the ſtick, or of a piece of timber, be it ever ſo long, the man will hear the beating of the watch very diſtinctly; whereas in the uſual way through the air, he can hardly hear it from a greater diſtance than about 15 feet.

The ſame effect will take place if he ſtops both his ears with his hands, and reſts his teeth, his temple, or the cartilaginous part of one of his ears againſt the end of the ſtick.—Inſtead of a ſtick he may uſe a rod of iron or other metal, a block or pillar of marble, &c.

Inſtead of applying the watch, a very gentle ſcratch may be made at one end of a pole, or rod, and the perſon who keeps the ear in cloſe contact with the other end of the pole, after the above-mentioned manner, will hear it with great accuracy.

Thus perſons who are not quick of hearing, by applying their teeth to ſome part of an harpſichord, or other ſounding body, will, by that means, be enabled to hear the ſound much better than otherwiſe.

If a man ſtops his ears with his hands, then paſſes the loop of a ſtring (which has a piece of metal, as a ſpoon, &c. tied to its extremity) over his head and hands, and by ſtooping himſelf a little, keeps the end of the ſtring, with the ſpoon or piece of metal, pendant before him; on ſtriking the ſpoon

againſt

againſt any thing, he will hear a ſound not much different from that of a large bell.—Such experiments are capable of great variety *.

It has been ſaid, that the report of cannons fired at Toulon may be heard at Monoco, viz. at the diſtance of about 76 miles, by a perſon lying on the ground; but not otherwiſe. But the practice of placing one's ear cloſe to the ground, in order to perceive the approach of horſes or men; or, in ſhort, for the purpoſe of hearing diſtant ſounds, has been obſerved even amongſt uncivilized nations.

Articulate ſounds may alſo be tranſmitted through ſolids; but I muſt own, they are not perceived very diſtinctly by my ear. However, Dr. Chladni, who has made a vaſt number of experiments relative to this ſubject, expreſſes himſelf in the following manner:

" Articulated tones alſo are conducted exceedingly well through hard bodies, as I found by experiments which I made with ſome of my friends. Two perſons who had ſtopped their ears, could converſe with each other when they held a long ſtick, or a ſeries of ſticks, between their teeth, or reſted their teeth againſt them. It is all the ſame whether the perſon who ſpeaks reſts the ſtick againſt his throat or

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* See the Mem. of the Ac. of Turin, for 1790 and 1791.

“ his breaſt, or when one reſts the ſtick which he
“ holds in his teeth againſt ſome veſſel into which
“ the other ſpeaks. The effect will be greater
“ the more the veſſel is capable of a tremulous
“ movement. It appeared to be ſtrongeſt with
“ glaſs and porcelain veſſels; with copper kettles,
“ wooden boxes, and earthen pots, it was weaker.
“ Sticks of glaſs, and next fir-wood, conducted the
“ ſound beſt. The ſound could alſo be heard
“ when a thread was held between the teeth by
“ both, ſo as to be ſomewhat ſtretched. Through
“ each ſubſtance, the ſound was modified in a
“ manner a little different. By reſting a ſtick or
“ other body againſt the temples, the forehead, and
“ the external cartilaginous part of the ear, ſound
“ is conveyed to the interior organs of hearing, as
“ will readily appear if you hold your watch to
“ thoſe parts of another perſon who has ſtopped up
“ his ears. From this it appears, as well as from
“ the experiments relative to the hearing under
“ water, that hearing is nothing elſe than, by
“ means of the organs of hearing, to be ſenſible
“ of the tremulous movement of an elaſtic body,
“ whether this tremulous movement be conveyed
“ through the air, or any other fluid or hard body,
“ to the auricular nerves. It is alſo eſſentially the
“ ſame whether, as is uſually the caſe, the ſound
“ be conveyed through the internal part of the
“ ear, or whether it be communicated through
“ any other part of the body. It certainly would

" be worth the trouble to make experiments to
" try whether it might not be poſſible that deaf and
" dumb people, when the deficiency lies only in
" the external organs of the ear, the auricular
" nerve being perfect, could not, by the above
" method of conducting ſound, be made to hear,
" diſtinctly, words articulated, as well as other
" ſounds*."

The velocity with which ſound moves through ſolids, is by no means known, nor does it ſeem likely to be determined experimentally; for ſuch experiments can only be performed with ſeveral hundred feet length of each particular ſubſtance. The only thing which has been tried relative to this ſubject, is to tranſmit a ſound through a ſeries of pieces of wood placed in cloſe contact the firſt with the ſecond, the ſecond with the third, and ſo on. It was found that ſound is tranſmitted through wood faſter than through air; but it could not be determined how much faſter†.

Whether

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[*] This has been taken from the Phil. Mag. for July 1799, which contains the tranſlation of ſome paſſages extracted from Dr. Chladni's original work on the longitudinal vibrations of ſtrings, &c.

[†] By reaſoning and calculation it has been deduced, that a column of air in a pipe of a certain length, open at both ends, makes one longitudinal vibration in the ſame time that ſound would employ to percur the ſame length of air;

Whether ſound be tranſmitted at all through vacuum, or not, is by no means determined. A bell incloſed in a glaſs receiver, and cauſed to ſound, can be heard leſs and leſs, according as the glaſs is more and more exhauſted of air; but though I have uſed one of the beſt air-pumps that was ever conſtructed, and the apparatus which ſupported the bell was laid upon ſuch ſoft ſubſtances as ſeemed leaſt likely to tranſmit the ſound through them; yet I could never render the ſound of the bell quite unaudible. Beſides, it may be ſuſpected, that when the glaſs receiver is exhauſted of air, the preſſure of the atmoſphere, on its outſide only, may check in great meaſure the tranſmiſſion of the ſound. If it be aſked what can tranſmit the ſound, or the vibrations of the bell, when the air between it and the glaſs has been removed, ſuppoſing that it might be entirely removed? We muſt undoubtedly aſſert our ignorance of it. But our ignorance of what may tranſmit the ſound in that caſe, does not prove that

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air; (*Riccati delle fibre elaſtiche.* Newton's Princ. L. 2. Prop. 50.) hence it may be preſumed, by analogy, that ſound is tranſmitted by ſolids of a certain length in the ſame time in which thoſe ſolids would perform each of their longitudinal vibrations. Now it has been found that a rod of iron of a certain length, will perform its longitudinal vibrations much faſter than an equal pillar of air; therefore it is likely that ſound will move through iron much faſter than through air, and the ſame thing may be ſaid of other ſolids.

the ſound could not be heard if the air were entirely removed.

Sounds diminiſh in intenſity, or they are leſs audible, according as the hearers are farther from the ſounding body; but there is no accurate method of determining this decreaſe*.

The ſame ſound is ſtronger in denſe than in thinner air. The actual fall of rain, ſnow, &c. or a good deal of moiſture in the air, diminiſh the intenſity of ſound. In calm, ſerene weather, when every thing is quiet, a ſound is heard much ſtronger, and of courſe much farther than otherwiſe. When a ſmooth ſurface of ground, and eſpecially of water, is interpoſed between the ſounding body and the hearer, then ſounds may be heard much farther than when water much agitated, or ground covered with houſes, trees, &c. is interpoſed.

In favourable circumſtances the ſtriking of the clock on the bell of St. Paul's church, in London, has been heard at Windſor. It has been ſaid that with a particular concurrence of favourable circumſtances, the human voice has been heard at the diſtance of more than ten miles, viz. from Old Gibraltar to New Gibraltar†. The diſcharge of an ordinary muſket can hardly ever be heard farther

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* See the Phil. Tranſ. for 1800, p. 120.

† Derham's Phyſico-Theology, B. IV. chap. 3. See alſo the Phil. Tranſ. N. 300, for more facts of this nature.

than ſeven or eight miles; but the diſcharge of ſeveral ſuch muſkets at the ſame time may be heard from a greater diſtance. The quick repetition of the ſame ſound may alſo be heard ſomewhat farther than the ſame ſingly. In the Dutch war of the year 1672, it has been ſaid, that the reports of cannons were heard at the diſtance of 200 miles, and upwards.

It is commonly ſaid, that the vibrations, which are communicated to the air by a ſounding body, expand ſpherically all round that body; and in fact its ſound may be heard on any ſide of it; yet certain it is, that the ſound will not be heard with equal force and diſtinction in every direction; and this difference is much greater with certain ſounding bodies, (viz. when a ſtrong impulſe is given to the air in a particular direction) than with others. The report of a cannon appears louder to a perſon towards whom it is fired, than to one ſituated in a contrary direction*. The ſpeaking trumpet throws the ſound directly before its aperture, and very little of it can be heard by perſons who are out of that direction†. In windy weather the

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* Phil. Tranſ. for 1800, p. 118.

† Upon this principle ſeveral curious contrivances may be made; and the ſpeaking of the inanimate figure, ſuſpended in the air, which was exhibited in London ſome years

the ſound of a diſtant bell is perceived to increaſe or decreaſe in loudneſs, according as the wind alters

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years ago, depends upon the ſame principle. The mechaniſm was as follows: A wooden figure was ſuſpended in the air by means of ribbands, in an opening between two rooms. There was a perforation about an inch and a half in diameter, from the mouth to the upper part of the head. This aperture had an enlarged termination on the top of the head, and with the other extremity communicated with a ſort of ſpeaking-trumpet, which was faſtened to the mouth of the figure. Behind the partition the enlarged or funnel-like opening of a tube was ſituated directly oppoſite to, and at about two feet diſtance of, the aperture on the head of the figure. The tube behind the partition was bent in a convenient form, and a concealed performer applied either his mouth or his ear to the other end of the tube. Now, if a perſon applied his mouth to the opening of the trumpet, and ſpoke into it, the ſound paſſed from the opening on the head of the figure through the air, to the opening of the tube which ſtood facing it behind the partition of the rooms, and the perſon, who applied his ear to the farther opening of the tube, would hear it diſtinctly; but other perſons in the room heard very little, if at all, of the ſaid articulated ſound; and the ſame thing took place, when the concealed perſon ſpoke with his mouth cloſe to the fartheſt end of the tube, and another perſon placed his ear cloſe to the opening of the trumpet; which ſhews that the ſound paſſed almoſt entirely in a ſtraight direction, from the opening on the head, to the oppoſite aperture of the tube, and *vice verſa.* This made it appear as if the wooden figure itſelf comprehended words, and returned an adequate anſwer.

its ſtrength or its direction. An obſtruction to the direction of ſounds, is evidently made by hills, houſes, large trees, and other bodies of a certain extent; for the ſound of a diſtant bell, of a mill, of the waves of the ſea on the ſhore, &c. may be heard much better when nothing ſolid is interpoſed between the hearer and the ſounding body, than otherwiſe. This may be eaſily obſerved by a perſon walking through a town, when a noiſe proceeds from any of the above-mentioned cauſes; for he will hear the noiſe much better when he comes to the opening of a ſtreet which leads to the ſounding place, than when the houſes intervene; ſo that the ſound which comes out of an aperture, does not expand ſpherically round that aperture, as round a centre; and this is analogous to what has been ſaid with reſpect to the direction of a ſtream of water, which comes out of an aperture (ſee p. 178.); but it muſt be confeſſed, that we are leſs able to comprehend the real motion of the air, than that of the waves on the ſurface of water, or that of a ſtream.

Sounds are alſo reflected by hard bodies, and this reflection produces the well-known phenomenon, called the *echo*; and others analogous to it.

If a perſon ſtanding at a certain diſtance before a high wall, a bank, a rock, &c. utters a word or makes a noiſe, either with his voice or with an hammer, &c. he will frequently hear a repetition of the word or other noiſe; and the time which elapſes

elapſes between the expreſſion of the ſound and the hearing of the ſame again, is the ſame as ſound in general would employ in going twice through the diſtance between the man and the wall, or the rock, &c. for the vibrations of the air muſt go from the man to the wall, and back again; ſo that if the wall be 1142 feet diſtant, the time elapſed between the expreſſion of the ſound, and the ſecond arrival of it to the ear, will be two ſeconds; and ſo forth.

But the ſame original ſound, and the repetition of it, which is called the *echo*, may be heard by other perſons ſituated at different diſtances both from the original ſounding place, and from the reflecting wall, or other object. The effect, however, will not be exactly alike; for inſtance, thoſe who are nearer to the wall, will hear the echo ſooner than other perſons; thoſe who are as far again from the man who expreſſes the ſound as they are from the reflecting obſtacle, when the reflecting object is at an equal diſtance from both, will hear both the original ſound and the echo at the ſame time; in which caſe they will perceive, as it were, one ſound louder than they would without the repetition.

But though ſeveral perſons in different ſituations will hear the echo or repetition of the ſame ſound; yet in a particular direction, the echo may be heard much better than in other directions. Now, if two ſtraight lines be drawn from the centre or middle of the

the reflecting ſurface, one to the place whence the original ſound proceeds, and another in the abovementioned beſt direction; thoſe lines will be found to make equal angles with, or to be equally inclined to, that ſurface. Hence it is ſaid, *that ſound is reflected by certain bodies, and that the angle of reflection is equal to the angle of incidence.*

This ſhews, that though ſound proceeds from an original ſounding body, or from a reflecting ſurface, in every direction; yet a greater quantity of it proceeds in ſome particular direction than in any other; and this is probably owing to the original impulſe being given to the air in one direction more forcibly than in others, as alſo to the want of perfect freedom of motion in the aërial fluid.

The ſurface of various bodies, ſolids as well as fluids, have been found capable of reflecting ſounds, viz. the ſides of hills, houſes, rocks, banks of earth, the large trunks of trees, the ſurface of water, eſpecially at the bottom of a well, and ſometimes even the clouds. It is therefore evident, that in an extenſive plain, or at ſea, where there is no elevated body capable of reflecting ſounds, no echo can be heard.

The configuration of the ſurface of thoſe bodies ſeems to be much more concerned in the production of the echo, than the ſubſtance itſelf. A ſmooth ſurface reflects ſounds much better than a rough one. A convex ſurface is a very bad reflector of ſound; a flat ſurface reflects it very well; but

but a ſmall degree of concavity, and eſpecially when the ſounding body is in the centre, or focus, of the concavity, renders that ſurface a much better reflector.

Thus in an elliptical chamber, if the ſounding body be placed in a focus of the ellipſis, that ſound will be heard much louder by a perſon ſituated in the other focus, than in any other part of the chamber. In this caſe the effect is ſo powerful, that even when the middle part of the chamber is wanting, viz. when the two oppoſite elliptical ſhells only exiſt, the ſound expreſſed in one focus will be heard by a perſon ſituated in the other focus, but hardly at all by other perſons*.

This in ſome meaſure explains the effect of what are called *whiſpering domes*, and *whiſpering galleries*; wherein, if a perſon ſpeaks pretty near the wall on one ſide of it, another perſon will hear him diſtinctly when he places his ear pretty near the wall on the oppoſite ſide. The dome in St. Paul's cathedral, in London, has this curious property,

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* If from any point in the circumference of an ellipſis, two lines be drawn to the foci, thoſe lines make equal angles with the curve at that point. This is demonſtrated by all the writers on conics. Therefore, the ſound which is produced in one focus of an elliptical chamber, and is reflected from the wall to the other focus, makes all the angles of incidence equal to the angles of reflection reſpectively. Hence, that focus is the place where the ſound is heard beſt.

which is generally ſhewn to all enquiring viſitors.

Several phenomena may be explained ſo eaſily upon the above-mentioned theory of the reflection of ſound, that they need be merely mentioned to the intelligent reader.

Several reflecting ſurfaces frequently are ſo properly ſituated with reſpect to diſtance, and direction, that a ſound proceeding from a certain point, is reflected by one ſurface firſt, then by another which is a little farther off, after which it is reflected by a third ſurface, and ſo on; or it is reflected from one ſurface to a ſecond, from the ſecond to a third, from the third to a fourth, &c. Hence, echos, which repeat the ſame ſound, or the ſame word, two or three, or ſeveral times over, are frequently met with.

According to the greater or leſs diſtance from the ſpeaker, a reflecting object will return the echo of ſeveral, or of fewer ſyllables; for all the ſyllables muſt be uttered before the echo of the firſt ſyllable reaches the ear, otherwiſe it will make a confuſion. In a moderate way of ſpeaking, about 3½ ſyllables are pronounced in one ſecond, or ſeven ſyllables in two ſeconds*. Therefore, when an echo repeats

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* From the computation of ſhort-hand writers it appears that a ready and rapid orator in the Engliſh language, pronounces from 7000 to 7500 words in an hour, viz. about 120 words in a minute, or two words in each ſecond. Memoirs of Gibbon's Life.

ſeven ſyllables, the reflecting object is 1142 feet diſtant; for ſound travels at the rate of 1142 feet per ſecond, and the diſtance from the ſpeaker to the reflecting object, and again from the latter to the former, is twice 1142 feet. When the echo returns 14 ſyllables, the reflecting object muſt be 2282 feet diſtant, and ſo on. A famous echo is ſaid to be in Woodſtock Park, near Oxford. It repeats 17 ſyllables in the day, and 20 at night*. Another remarkable echo is ſaid to be on the north ſide of Shipley church, in Suſſex. It repeats diſtinctly, in favourable circumſtances, 21 ſyllables †.

Therefore the farther the reflecting ſurface is, the greater number of ſyllables the echo will repeat; but the ſound will be enfeebled nearly in the ſame proportion, and at laſt the ſyllables cannot be heard diſtinctly.

When the reflecting object is too near, the repetition of the ſound arrives at the ear, whilſt the perception of the original ſound ſtill continues, in which caſe an indiſtinct reſounding is heard. This effect may be frequently obſerved in empty rooms, paſſages, &c. eſpecially becauſe in ſuch places ſeveral reflections from the walls to the hearer, as alſo from one wall to the other, and then to the

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* Dr. Plot's Nat. Hiſt. of Oxfordſhire.

† Harris's Lex. Tech. Article Echo.

hearer, claſh with each other, and increaſe the indiſtinction.

If each of the vibrations of the air, which are occaſioned by a certain ſound, be performed in the ſame time that ſound employs in going from the ſounding body to the walls of a room, and thence to the hearer, then the ſound will be heard with greater force. In ſhort, by altering our ſituation in a room and expreſſing a ſound, or hearing the ſound of another perſon, in different ſituations, or when different objects are alternately placed in the room, that ſound may be heard louder or weaker, and more or leſs diſtinct. Hence it is, that blind perſons, who are under the neceſſity of paying great attention to the perceptions of their ſenſe of hearing, acquire the habit of diſtinguiſhing, from the ſound even of their own voices, whether a room is empty or furniſhed, whether the windows are open or ſhut, and ſometimes they can even diſtinguiſh whether any perſon be in the room or not*.

A great

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* The famous Dr. N. Saunderſon, Profeſſor of the Mathematics in the univerſity of Cambridge, who had been blind ſince he was one year old, poſſeſſed ſuch acuteneſs of hearing, that, as is related in the account of his life, "By "his quickneſs in this ſenſe, he not only diſtinguiſhed per-"ſons, with whom he had ever once converſed, ſo long as "to fix in his memory the ſound of their voice, but in ſome "meaſure places alſo. He could judge of the ſize of a room "into

A great deal of furniture in a room, eſpecially of a ſoft kind, ſuch as curtains, carpets, &c. check in great meaſure the ſounds that are produced in it; for they hinder the free communication of the vibrations of the air, from one part of the room to the other.

The fitteſt rooms for declamation, or for muſic, are ſuch as contain few ornaments that obſtruct the ſound, and at the ſame time have the leaſt echo poſſible; for when they have one or more echos, which ariſe from cupolas, alcoves, vaulted ceilings, &c. the repetition of one or more ſounds comes to the ear at the ſame time that another direct ſound reaches it, which not only ſpoils the former, but nine times out of ten forms a diſcord.

A pretty ſtrong and continued ſound fatigues the ear. The ſtrokes of heavy hammers, of artillery, &c. are apt to render people deaf, at leaſt for a certain time. And it has been obſerved, that ſome perſons who have been long expoſed to the continued and confuſed noiſe of certain manufactories, or of water-falls, or of other noiſy places, can hear

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" into which he was introduced, of the diſtance he was " from the wall: and if ever he had walked over a pavement in courts, piazzas, &c. which reflected a ſound, and " was afterwards conducted thither again, he could exactly " tell whereabouts in the walk he was placed, merely by the " note it ſounded."

what is ſpoken to them, much better in the midſt of that noiſe than elſewhere.

The attentive reader may naturally enquire in what manner are ſounds communicated to our ſenſorium, and in what manner does the ear receive and tranſmit them to the auditory nerve; but to thoſe queſtions I am unable to give any ſatisfactory anſwer. A particular deſcription of the internal, as well as external, parts of the ear, may be found in a variety of anatomical books; but the knowledge of the conſtruction does not inform us of the real uſe of thoſe parts. The form of the external part of the ear is evidently intended for receiving in great quantity, and for concentrating the vibrations of the air.

Some very remarkable obſervations lately made, relative to the organ of hearing, ſhew, in a very pointed manner, that the various functions of that organ are far from being rightly underſtood*. A proper inveſtigation of the ſubject is highly recommendable to every able philoſopher.—It might doubtleſs improve the general ſubject of acouſtics, and in particular it might furniſh means of remedying, or of ſupplying, the defects incident to the human ear.

The only known mechanical method of improving that organ, when it is in a certain manner defective, is by the uſe of the *hearing-trumpet*.

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* See Mr. Aſtley Cooper's Paper, in the Phil. Tranſ. for 1800, page 151.

This trumpet is an hollow conical tube, from about 8 to 16 inches in length. It is often bent not much unlike the letter C, excepting that in general the ſmall end is bent much leſs than the other. The ſmall end (whoſe aperture is not above a quarter of an inch in diameter) is applied to the ear, whilſt the large aperture (which is from about 2 to 4 inches in diameter) is directed towards a ſpeaker, or towards the ſounding body. By this means the ſound is heard conſiderably louder, but leſs diſtinct.

Hearing trumpets have been made of various ſhapes, though the above ſeems upon the whole to be the beſt; but no theory can at preſent determine their moſt advantageous conſtruction.

Their office is to increaſe, not the frequency, but the momentum of the aërial vibrations; and this may probably ariſe from thoſe vibrations paſſing gradually from the larger to the narrower part of the inſtrument. Perhaps the vibrations of the air reflected from different points of the inſtrument, like different echos, reach the ear not all preciſely at the ſame time; hence the ſound is rendered louder, but leſs diſtinct. I ſhall not however proceed to explain what I myſelf do not clearly underſtand.

CHAPTER XII.

OF MUSICAL SOUNDS.

A Succeſſion of ſounds has been called *Melody*.

The compound effect which ariſes from two ſounds, expreſſed at the ſame time, is called *Conſonance*, or *Diſſonance*, according as it produces a pleaſing or unpleaſing effect.

An *Accord* is the effect which ariſes from, or a combination of, more than two ſounds expreſſed at the ſame time.

A ſucceſſion of accords is called *Harmony*.

The art which examines, diſpoſes, and expreſſes ſounds, ſo as to produce melody, or harmony, pleaſing upon the whole, is called *Muſic*, or the *Muſical Art*. And the ſounds, which are ſo far ſimple, determinate, and pleaſing, as to be uſed in muſic, are called *Muſical Sounds*.

It has been ſaid, at the beginning of the preceding chapter, that the variety of ſounds ariſes from three cauſes principally, viz. 1ſt, from the greater or leſs frequency of the vibrations; 2dly, from the quantity, force or momentum of the vibrating parts; and 3dly, from the greater or leſs ſimplicity of each ſound.

A clear idea of thoſe differences may be conceived by comparing the ſound of a pretty large bell, with that of a ſtring of a baſe viol. Thoſe two ſonorous bodies may be adjuſted ſo, that each of them may perform the ſame number of vibrations in the ſame time. In that caſe the ſounds of thoſe inſtruments are ſaid to be of the ſame *pitch*; for the pitch of a certain ſound, or of the inſtrument which expreſſes that certain ſound, is ſaid to be equal to, lower, or higher than the pitch of another ſound, or other ſonorous body that emits that ſound, when the firſt ſonorous body performs an equal, a ſmaller, or a greater number of vibrations than the other ſonorous body in the ſame time.

But though thoſe inſtruments expreſs the ſame ſound with reſpect to the pitch; yet the ſound of the bell is much louder than that of the baſe viol; and, in fact, the former may be heard from a much greater diſtance than the latter. This ſhews the ſecond diſtinction *.

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* The greater or leſs ſtrength of a ſound of the ſame pitch is called by muſicians, the *forte* and *piano* of that ſound. The well known inſtrument, called the *forte piano*, derives its name from its being capable of expreſſing the ſame tones more or leſs loud; whereas the harpſichord, which is like the forte piano in every other reſpect, expreſſes its tones always of the ſame ſtrength.

The third ariſes from the inequality, harſhneſs, &c. of the ſound of the bell in compariſon with that of the baſe viol; for a perſon, who is ſufficiently near, and liſtens with attention, will perceive that the ſound of the bell is attended with a ſort of undulation, both in pitch and ſtrength; and is, beſides, accompanied with one or more ſecondary ſounds; whereas the ſound of the baſe viol is much more ſimple and uniform.

There is no method of meaſuring the quantity of the above-mentioned ſecond and third diſtinctions; excepting by the judgment of the ear, which is various and partial. One perſon, for inſtance, prefers the ſound of a powerful organ to that of a violin; another prefers the latter to the former. One likes the ſound of a French horn above that of all other inſtruments, and another prefers a flute.

In general it is not from a proper diſcrimination, but from the various acuteneſs of the ear, from prejudice, from faſhion, from want of diſcernment, or from miſtaken ideas, that moſt people expreſs their likings and diſlikings. Various and diſcordant are the opinions of men relatively to thoſe things which have no fixed ſtandard of perfection or demonſtration; yet it may be preſumed, eſpecially with reſpect to muſical ſounds, that whatever pleaſes the majority, and whatever can be endured for a longer time without diſguſt, is the beſt and the moſt eligible. And there are ſome perſons who, from knowledge, practice, ſenſibility, and a proper uſe of their reaſoning faculty, have enabled themſelves to diſcriminate at once between what is, and what is not, more likely to pleaſe the majority, or to be endured longer without diſguſt.

After a long and diverſified experience, through a conſiderable ſeries of years, it has been found, that certain ſounds, expreſſed in certain ſucceſſions, and in certain combinations, are pleaſing to moſt human ears. They are of the ſimpleſt and moſt uniform kind, neither too loud, nor too feeble; but differing from each other in pitch, by certain fixed and determinate intervals.—They are called *muſical ſounds*, or *tones*.

Beſides the human voice, ſeveral inſtruments, which have been invented at various times, and are now in uſe, are capable of expreſſing thoſe muſical ſounds; hence they are called *muſical inſtruments*, and the beſt of them are ſuch as are capable of expreſſing the greateſt variety of ſuch ſounds, eſpecially with reſpect to the pitch, and of the ſimpleſt, as well as of the moſt pleaſing ſort.

Upon ſome of thoſe inſtruments, ſuch as the harpſichord, forte piano, the organ, the guitar, &c. the pitch of each tone is fixt and immutable. In others, ſuch as the human voice, French horn, violin, violoncello, &c. the pitch proper for each tone, muſt be determined by the performer. The accompliſhment of this taſk is very difficult; and from

from this are the muſical performers ſaid to have a *good* or a *bad intonation.*

What has been ſaid above may ſuffice with reſpect to the leſs definite qualities of ſounds; viz. ſtrength and ſimplicity. It is now neceſſary to treat of the more difficult, but more determinate, quality, called the *pitch*, which has already been ſaid to depend upon the frequency of the vibrations.

The human voice, in its ordinary way of ſpeaking, generally changes its pitch by imperceptible intervals, or rather by ſliding a little way up or down. But there are different and conſiderable intervals between the muſical tones. Thoſe muſical tones were perhaps in great meaſure found out experimentally; but they have afterwards been reduced to, and may be expreſſed by means of, accurate mathematical meaſurements.—The order, or the arrangement, of thoſe ſounds is called *the ſcale of muſic*.

A voice or an inſtrument, which expreſſes thoſe ſounds in a particular order under certain reſtrictions, produces muſic; otherwiſe the effect is not pleaſing, nor is it called muſic. The natural ſinging of birds may exhibit a fine voice in certain caſes; but it is not muſical, their ſounds having nothing to do with the muſical intervals; and, in fact, the arrangement of their various ſounds is by no means pleaſing.

The number of vibrations which may be performed by a ſtretched ſtring, when its tenſion, length, and weight are known, may be aſcertained with tolerable accuracy.

The number of vibrations of moſt other ſounding bodies, cannot be aſcertained otherwiſe than by comparing their ſounds with thoſe of ſtringed inſtruments; for the human ear can judge with conſiderable accuracy when the two inſtruments are in uniſon, or perform contemporaneous vibrations, in which caſe they are ſaid to be *of the ſame pitch*; and indeed ſome expert muſicians can determine by the judgment of their ear, not only when two ſounds are of the ſame pitch, but alſo when they are at a certain diſtance of each other. Therefore, in our inveſtigation and expreſſions of muſical ſounds, it will be ſufficient to ſpeak of ſtretched ſtrings or chords only; as the ſounds of all the other inſtruments may be referred to thoſe of ſtrings.

The following particulars relative to ſtretched ſtrings have been demonſtrated mathematically, and the demonſtration will be found in the following note, for the uſe of thoſe readers who are ſufficiently ſkilled in mathematics.

1. If a ſtretched cylindrical chord be ſtruck, and then be left to vibrate by itſelf, it will perform its vibrations, whether large or narrow, in equal times, and, of courſe, the ſound, though decaying gradually, yet continues in the ſame pitch; excepting, however, when the ſtring is ſtruck violently; for in that caſe its ſound is a little higher at firſt,

viz. its vibrations are a little more frequent at firſt.

2. If various ſtrings be equally ſtretched, and be of the ſame ſubſtance; or, in ſhort, if they be equal in every reſpect, excepting in their lengths; then the duration of a ſingle vibration of each ſtring will be as the length of the ſtring; or (which is the ſame thing) the number of vibrations performed by each ſtring in a given time, will be inverſely as the length; for inſtance, if a ſtring be four feet long, and another ſtring, *cæteris paribus*, be one foot long; then the latter will vibrate four times whilſt the former vibrates once. Or if the length of the former be to that of the latter, as 10 to 3; then the vibrations performed by the latter will be to thoſe that are performed by the former, as 3 to 10; and ſo on. Alſo, the ſame thing muſt be underſtood of the parts of the ſame ſtring; for inſtance, if a certain ſtring perform 8 vibrations in a ſecond; then, if that ſtring be ſtopped in the middle, and one half of it only be cauſed to ſound, then that half will perform 16 vibrations in a ſecond.—One third part of the ſame ſtring will perform 24 vibrations in a ſecond; and ſo on.

The length of the ſtring is reckoned from one bridge to the other, or from one reſting place to the other; thus, in fig. 19. Plate XIII. the length of the ſtring is reckoned from R to S. The tenſion of the ſtring is meaſured by the weight *w*, which is ſuſpended to one end of it. If inſtead of ſtretching a ſtring by ſuſpending a weight to it, as indicated by the above-mentioned figure, the ſtring be twiſted round a peg, after the manner commonly uſed in muſical inſtruments, then the tenſion ſtill muſt be expreſſed by a weight; meaning a weight which may be capable of ſtretching the ſtring as much as it is ſtretched by turning the peg.

3. If various chords differ in tenſion only; then the number of vibrations which each of them performs in a given time, is as the ſquare root of the ſtretching weight. Thus, if a chord be ſtretched by a weight of 16 pounds, and another chord be ſtretched by a weight of 9 pounds; then the former will perform 4 vibrations in the ſame time that the latter performs 3 vibrations.

4. If cylindrical chords differ in thickneſs only; then the number of vibrations which they perform will be inverſely as the diameters, viz. if the diameter of a chord be equal to twice the diameter of another chord; then the former will perform one vibration in the ſame time that the latter performs two vibrations.

5. By a proper adjuſtment of the lengths, thickneſſes, and ſtretching weights, diſſimilar chords may be cauſed to perform any required number of vibrations; which is evidently derived from the preceding paragraphs.

6. The

6. The actual number of vibrations, which are performed by a given ſtretched chord, may be determined, without any great error, by uſing the following rule; provided the length and weight of the vibrating part of the chord, as RS, fig. 19, and likewiſe the ſtretching weight *w*, be known.—*Rule.* Multiply the ſtretching weight by 39,12 inches (which is nearly the length of the pendulum that vibrates ſeconds). Alſo multiply the weight of the chord by its length in inches; divide the firſt product by the ſecond; extract the ſquare root of the quotient; multiply this ſquare root by 3,1416, and this laſt product is the number of vibrations that are performed in one ſecond of time by the given chord.—The reſiſtance of the air, as alſo ſome other fluctuating cauſes of obſtruction, not being noticed in this rule; it is moſt probable that the real vibrations are not quite ſo numerous as they are given by the rule.

An example of the above-mentioned rule.—A copper wire of 35,55 inches in length, weighing 31 grains troy, was ſtretched by a weight of ſeven pounds avoirdupois, which is nearly equal to 49000 grains. How many vibrations did it perform in each ſecond?—The product of 49000 multiplied by 39,12 is 1916880. The product of 35,55 by 31, is 1102,05. If 1916880 be divided by 1102,05, the quotient will be 1739,37, the ſquare root of which is 41,7; and

and this ſquare root being multiplied by 3,1416, gives 131 for the required number of vibrations. (1.)

It

(1.) It is evident from what has been ſaid above, that by diminiſhing the tenſion and increaſing the length of the chord, the number of vibrations may be diminiſhed to ſuch a degree as to render the ſingle vibrations diſcernible from each other; hence it ſeems, that the vibrations of a chord that expreſſes a certain tone, might be counted; but in practice the performance of ſuch experiments is attended with very great, and hitherto unſurmounted, difficulties. Several perſons have tried the experiment; but no deciſive reſults have ever been derived therefrom.

I have attempted ſuch experiments, both with metallic and with catgut ſtrings of various ſizes and lengths, as far as 17 feet; and with various degrees of tenſion, or with various ſtretching weights. I have uſed thoſe ſtrings in the manner of pendulums, with a weight faſtened to the lower extremity;—I have alſo placed them horizontally, after the above-mentioned manner of fig. 19. Plate XIII; but the effect was, that when the vibrations were fewer than ten or twelve in a ſecond, which is the greateſt number I can poſſibly count with tolerable certainty; then the ſound of the chord was ſo very indiſtinct, equivocal, and encumbered with other ſounds, that I could not be certain of its pitch. If by increaſing the weight, or by ſhortning the chord, the tone was rendered ſufficiently diſtinct; then the vibrations were thereby quickened beyond the poſſibility of counting them.

Nevertheleſs, I ſhall ſubjoin the particulars of one of thoſe experiments, which was repeated ſeveral times, both by

It is now neceſſary to ſpecify thoſe ſounds which experience has ſhewn to be fit for muſical compoſition. And here we ſhall only ſpeak of the pitch, which is denoted by the number of vibrations that are

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by myſelf, and in the preſence of a very intelligent friend; hence it may be preſumed to be as accurate as the nature of the ſubject can admit of.

A braſs ſtring, ſuch as is uſed for harpſichords, was ſuſpended like a pendulum, with a weight of 5 ¾ pounds, (viz. 40250 grains) at its extremity.

The length of the ſtring was 100 inches. Its weight 130 grains; when ſtruck and ſet a vibrating, if a piece of paper was ſet on one ſide of it, the ſtring ſtruck the paper about 14 times in a ſecond, as nearly as I could poſſibly reckon. And as it would have ſtruck a piece of paper on the other ſide as often in the ſame time, therefore it performed 28 vibrations in a ſecond.

But, by calculation, it ought to have performed 34,56 vibrations in a ſecond.

When, inſtead of 5 pounds and ¾, one pound only, or 7000 grains, was ſuſpended to it, the ſtring performed from 10 to 12 vibrations in a ſecond; and in fact the numbers of vibrations being as the ſquares of the ſtretching weights, we have $\overline{40250}|^{\frac{1}{2}} : \overline{7000})^{\frac{1}{2}} :: 200,6 : 83,6 :: 28 : 11,6$; which is a pretty good agreement.

By calculation it ought to have performed 14,3 vibrations in a ſecond.

Therefore, it ſeems, that the method of determining the number of vibrations that are performed by a ſtring which ſounds a certain tone, muſt be derived from the theoretical demonſtration; but the reſult of ſuch demonſtration muſt deviate are performed in a given time, or by the length of the ſtring which emits each of thoſe ſounds; for it has been already ſhewn that, when ſtretched ſtrings are alike in all other reſpects, excepting in their lengths,

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deviate in a certain degree from the truth, principally on account of the reſiſtance of the air, and of the want of perfect pliability in the chord, &c.

The ratio which the number of vibrations bears to the weight, tenſion, length, &c. of the chord, has been demonſtrated, with ſome variation of method, by ſeveral able writers. The concluſion is always the ſame. I have, however, preferred Dr. Taylor's original demonſtration, ſuch as is publiſhed in the Philoſophical Tranſactions, becauſe it is leſs dependent upon other extraneous propoſitions, and of courſe it may be eſteemed the moſt conciſe.

It may be objected, that this demonſtration does not take in all the ſhapes which a ſtring, according to the various modes of ſtriking it, aſſumes in its vibrations. But it muſt be obſerved, that as, *cæteris paribus*, the ſame chord, however ſtruck, provided it be not ſtruck too violently, gives a tone conſtantly of the ſame pitch; its vibrations muſt be as frequent when it aſſumes the ſimpleſt, as when it aſſumes any other, form.

Of the Motion of a Stretched String, by Dr. B. Taylor.

Phil. Tranſ. N. 337. *or Jones's Abridg. vol. IV. p.* 391.

" *Lemma* 1. Let A D F B, A Δ Φ B, fig. 1. Plate XIV. be two curves, the relation of which is ſuch, that the ordinates lengths, then the duration of a ſingle vibration of each ſtring, is proportionate to the length of the ſtring; or, (which amounts to the ſame thing) that the number of vibrations performed by each ſtring

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ordinates $C\Delta D$, $E\Phi F$, being drawn, it may be $C\Delta : CD :: E\Phi : EF$. Then the ordinates being diminiſhed *ad infinitum*, ſo that the curves may coincide with the axis AB; I ſay, that the ultimate ratio of the curvature in Δ, will be to the curvature in D, as $C\Delta$ to CD."

"*Demonſt.* Draw the ordinate $c\delta d$ very near to CD, and at D and Δ draw the tangents Dt and $\Delta\theta$, meeting the ordinate cd in t and θ. Then becauſe of $c\delta : cd :: C\Delta : CD$, (by hypotheſis) the tangents being produced will meet one another, and the axis in the ſame point P. Whence, becauſe of ſimilar triangles CDP and ctP, $C\Delta P$ and $c\theta P$, it will be $c\theta : ct :: C\Delta : CD :: c\delta : cd$ (by hypoth.) $:: \delta\theta : (c\theta - c\delta) : dt\ (ct - cd)$ But the curvatures in Δ and D, are as the angles of contact $\theta\Delta\delta$ and tDd; and becauſe $\delta\Delta$ and dD coinciding with cC, thoſe angles are as their ſubtenſes $\delta\theta$, dt; that is, by the proportion above, as $C\Delta$, CD. Therefore, &c. Q. E. D."

"*Lemma* 2. In ſome inſtant of its vibration, let a ſtring, ſtretched between the points A and B, fig. 2. Plate XIV. put on the form of any curve $Ap\pi B$; I ſay, that the increment of the velocity of any point o, or the acceleration ariſing from the force of the tenſion of the ſtring, is as the curvature of the ſtring in the ſame point."

"*Demonſt.* Conceive the ſtring to conſiſt of equal rigid particles, which are infinitely little, as po, $o\pi$, &c. and at the ſtring in a given time, is inverſely as the length of the ſtring.

If you take ſeveral ſtrings preciſely of the ſame ſubſtance, the ſame form, and the ſame thickneſs, and

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the point o erect a perpendicular oR, equal to the radius of the curvature at o, which let the tangents pt, πt, meet in t, the parallels to them πs, ps, in s, the chord $p\pi$ in c. Then by the principles of mechanics, the abſolute force by which the two particles po and $o\pi$, are urged towards R, will be to the force of tenſion of the ſtring, as st to tp; and half this force by which one particle po is urged, will be to the tenſion of the ſtring, as ct to tp; that is, (becauſe of ſimilar triangles ctp, tpR) as tp or op to Rt, or oR. Wherefore, becauſe of the force of tenſion being given, the abſolute accelerating force will be as $\frac{op}{oR}$, But the acceleration generated is in a compound ratio of the ratios of the abſolute force directly, and of the matter to be moved inverſely; and the matter to be moved is the particle itſelf op. Wherefore the acceleration is as $\frac{1}{oR}$; that is, as the curvature in o. For the curvature is reciprocally as the radius of curvature in that point. Q. E. D."

"*Prob.* 1. To determine the motion of a ſtretched ſtring."

"In this and the following problem, I ſuppoſe the ſtring to move from the axis of motion through an indefinitely little ſpace; that the increment of tenſion from the increaſe of the length, alſo the obliquity of the radii of curvature, may ſafely be neglected."

"Therefore

and ſtretch them equally by ſuſpending equal weights to their extremities, or otherwiſe; then make their lengths of the proportions that are ſtated in the following table; thoſe ſtrings, when ſtruck, will expreſs

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"Therefore let the ſtring be ſtretched between the points A and B, fig. 3. Plate XIV. and with a bow let the point z be drawn to the diſtance C z, from the axis A B. Then taking away the bow, becauſe of the flexure in the point C alone, that will firſt begin to move (by *Lem.* 2.) But no ſooner will the ſtring be bent in the neareſt points φ and *d*, but theſe points alſo will begin to move; and then E and *e*; and ſo on. Alſo becauſe of the great flexure in C, that point will firſt move very ſwiftly, and thence the curvature being increaſed in the next points D, E, &c. they will immediately be accelerated more ſwiftly; and at the ſame time the curvature in C being diminiſhed, that point in its turn will be accelerated more ſlowly. And in general, thoſe points which are ſlower than they ſhould be, being accelerated more, and the quicker leſs, it will be brought about at laſt, that the forces being duly attempered one with another, all the motions will conſpire together, and all the points will at the ſame time approach to the axis, going and returning alternately, *ad infinitum.*"

"Now that this may be done, the ſtring muſt always put on the form of the curve A C D E B, the curvature of which, in any point E, is as the diſtance of the ſame E η from the axis; the velocities of the points C, D, E, &c. being alſo in the ratio of the diſtances from the axis C z, D ϑ, E η, &c. For in this caſe the ſpaces C κ, D δ, E ε, &c. deſcribed in the ſame infinitely little time, will be as the velocities; that is, as the ſpaces deſcribed C z, D ϑ, &c. Wherefore expreſs the proper muſical ſounds or tones, and the whole ſet is called the *ſcale of muſic*.

The ſucceſſive expreſſion of thoſe muſical ſounds in any order, produces *muſical melody*, which may be good

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Wherefore the remaining ſpaces ϰ z, δ ϑ, ε η, &c. will be to each other in the ſame ratio. Alſo (by *Lem.* 2.) the accelerations will be to one another in the ſame ratio. By which means the ratio of the velocities always continuing the ſame with the ratio of the ſpaces to be deſcribed, all the points will arrive at the axis at the ſame time, and always depart from it at the ſame time. And therefore the curve A C D E B will be rightly determined. Q. E. D."

" Moreover the two curves A C D E B and A ϰ δ ε B, being compared together, by *Lemma* 1. the curvatures in D and δ will be as the diſtances from the axis D ϑ and δ ϑ; and therefore, by *Lemma* 2. the acceleration of any given point in the ſtring will be as its diſtance from the axis. Whence, (by Sect. 10. Prop. 51. of Newton's Principia) all the vibrations, both great and ſmall, will be performed in the ſame periodical time, and the motion of any point will be ſimilar to the oſcillation of a body vibrating in a Cycloid. Q. E. I."

" *Cor.* Curvatures are reciprocally as the radii of circles of the ſame degree of curvature. Therefore let *a* be a given line, and the radius of curvature in E will be equal to $\frac{aa}{E\eta}$."

" *Prob.* 2. The length and weight of a ſtring being given, together with the weight that ſtretches the ſtring, to find the time of a ſingle vibration."

" Let

good or bad. The contemporaneous expreſſion of two of them is called a *conſonance* or *diſſonance*, according as it produces a pleaſant or unpleaſant effect. A ſingle ſtring may be made ſucceſſively ſhorter

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"Let the ſtring be ſtretched between the points A and B, fig. 4. Plate XIV. by the force of the weight P, and let the weight of the ſtring itſelf be N, and its length L. Alſo let the ſtring be put in the poſition $AFpCB$, and at the middle point C, let CS, a perpendicular be raiſed, equal to the radius of the curvature in C, and meeting the axis AB in D; and taking a point p near to C, draw the perpendicular pc and the tangent pt."

"Therefore it appears, as in *Lemma* 2, that the abſolute force by which the particle pC is accelerated, is to the force of the weight P, as ct to pt; that is, as pC to CS. But the weight P is to the weight of the particle pC, in a ratio compounded of the ratios of P to N, and of N to the weight of the particle pC, or of L to pC; that is, as $P\times L$ to $N\times pC$. Therefore, compounding theſe ratios, the accelerating force is to the force of gravity, as $P\times L$ to $N\times CS$. Let therefore a pendulum be conſtructed, whoſe length is CD; then (by Sect. X. Prop. 52, of Newton's Principia) the periodical time of the ſtring will be to the periodical time of that pendulum, as $\sqrt{N\times CS}$ to $\sqrt{P\times L}$. But by the ſame propoſition, the force of gravity being given, the longitudes of the *pendula* are in a duplicate ratio of the periodical times. Whence $\frac{N\times CS\times CD}{P\times L}$, or writing $\frac{aa}{CD}$ for CS, (by *Cor.* Prob. 1.) $\frac{N\times aa}{P\times L}$ will be the length of a pendulum, the ſhorter and ſhorter, according to the proportions of the table; and thus a ſingle ſtring may expreſs all the various muſical ſounds; but in this caſe, two ſounds cannot be expreſſed at the ſame time.

In

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vibrations of which are iſochronous to the vibrations of the ſtring."

"To find the line a, let the abſciſs of the curve be A E $= z$, and the ordinate E F $= x$, and the curve itſelf A F $= v$, and C D $= b$. Then (by *Cor. Prob.* 1.) the radius of curvature in F will be $\frac{a\,a}{x}$. But $\dot{v}$ being given, the radius of curvature is $\frac{\dot{v}\,\dot{x}}{\ddot{z}}$. Whence $\frac{a\,a}{x} = \frac{\dot{v}\,\dot{x}}{\ddot{z}}$, and therefore $a\,a\,\ddot{z} = \dot{v}\,x\,\dot{x}$; and taking the fluents $a\,a\,\dot{z} = \frac{\dot{v}\,x^2}{2} - \frac{\dot{v}\,b^2}{2} + \dot{v}\,a^2$. Here the given quantity $-\frac{\dot{v}\,b^2}{2} + \dot{v}\,a^2$ is added, that it may be $\dot{z} = \dot{v}$ in the middle point C. And hence the calculus being compleated, it will be $\dot{z} = \frac{a^2\,\dot{x} - \frac{1}{2}\,b^2\,\dot{x} + \frac{1}{2}\,x^2\,\dot{x}}{\sqrt{a^2\,b^2 - a^2\,x^2 - \frac{1}{4}\,x^4 - \frac{1}{4}\,b^4 + \frac{1}{2}\,b^2\,x^2}}$. Now let b and x vaniſh in reſpect to a, that the curve may coincide with the axis, and it will be $\dot{z} = \frac{a\,\dot{x}}{\sqrt{b\,b - x\,x}}$. Now, with the centre C, and radius D C $= b$, fig. 5. Plate XIV. a quadrant of a circle D P E being deſcribed, and making C Q $= x$, and erecting the perpendicular Q P; then the arch D P being $= y$, it will be $\dot{y} = \frac{b\,\dot{x}}{\sqrt{b\,b - x\,x}} = \frac{b}{a}\,\dot{z}$."

"Whence

In ſome inſtruments, as the forte-piano, harpſichord, &c. each ſtring expreſſes a particular tone. In other inſtruments, ſuch as the violin, violoncello, &c. each ſtring is cauſed to expreſs ſeveral tones ſucceſſively, by ſtopping part of it with the fingers

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" Whence $y = \frac{b}{a} z$, and $z = \frac{a}{b} y$. And making $x = b = CD$, in which caſe it is alſo $y =$ quadrantal arch DPE, and $z = AD = \frac{1}{2} L$; it will be $\frac{1}{2} L = a \times \frac{DE}{CD}$, and $a = L \times \frac{CD}{2DE}$. Let it be therefore $CD : 2DE$: : diameter of a circle : circumference : : $d : c$; and it will be $aa = LL \times \frac{dd}{cc}$. Therefore this value being ſubſtituted for aa; $\frac{N}{P} \times L \times \frac{dd}{cc}$ will be the length of a pendulum, which will be iſochronous to the ſtring. Therefore let D be the length, whoſe periodical time is 1, and $\frac{d}{c} \sqrt{\frac{N}{P} \times \frac{L}{D}}$, will be the periodical time of the ſtring. Q. E. I."

" For the periodical times of pendulums are as the ſquare roots of their lengths."

Cor. 1. The number of vibrations of the ſtring in the time of one vibration of the pendulum D, is $\frac{c}{d} \sqrt{\frac{P}{N} \times \frac{D}{L}}$.

Cor. 2. Becauſe $\frac{d}{c} \times \sqrt{\frac{1}{D}}$ is given, the periodical fingers, and permitting a certain portion only to vibrate.

The Scale of Muſical Sounds, or of the proportional Lengths of the Strings, which emit thoſe Sounds, together with their Literal and Numerical Names, as alſo the Names of the Intervals between them; where T *ſtands for* Major Tone; t *for* Minor Tone; *and* H *for* Hemi-Tone.

1	C	Firſt	
			T
$\frac{8}{9}$	D	Second	
			t
$\frac{4}{5}$	E	Third	
			H
$\frac{3}{4}$	F	Fourth	
			T
$\frac{2}{3}$	G	Fifth	
			t
$\frac{3}{5}$	A	Sixth	
			T
$\frac{8}{15}$	B	Seventh	
			H
$\frac{1}{2}$	c	Octave	
			T
$\frac{8}{18}$	d	Ninth	
			t

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time of the ſtring is as $\sqrt{\frac{N}{P} \times L}$. And the weight P being given, the time is $\sqrt{N \times L}$. And the ſtrings being made of the ſame thread, in which caſe it is N as L, the time will be as L."

$\frac{4}{10}$	e	Tenth	
			H
$\frac{3}{8}$	f	Eleventh	
			T
$\frac{2}{6}$	g	Twelfth	
			t
$\frac{3}{10}$	a	Thirteenth	
			T
$\frac{8}{30}$	b	Fourteenth	
			H
$\frac{1}{4}$	C	Sixteenth, or Double Octave, &c. &c.	

This table might be continued to any length, and the law of continuation will appear from the following paragraphs, which will be found to contain the neceſſary explanations.

The fractions denote the relation of each ſtring or tone to the firſt, or to the key, note. The length of the firſt ſtring may be a foot, or a yard, or in ſhort of any other dimenſion; but then the other ſtrings muſt be made in due proportion to that length, which is called one or unity. For inſtance, if the firſt ſtring be a yard long (viz. 36 inches) then the next ſtring muſt be 32 inches in length; for 32 is equal to $\frac{8}{9}$ths of 36. This fraction likewiſe ſhews, that the ſecond ſtring performs nine vibrations, whilſt the firſt performs eight vibrations. Alſo the length of the fourth ſtring is marked $\frac{3}{4}$, meaning that it muſt be three-fourths of the firſt; and it ſhews, that this ſtring per-

performs four vibrations whilſt the firſt performs only three; and ſo of the reſt.

The letters which are annexed to the fractions in the ſecond column of the table, are the names by which muſicians diſtinguiſh the various tones; and the numerical names of the third column, ſhew the diſtance of each tone from the firſt, which is otherwiſe called the *key-note*, or *principal tone*. Thus the fifth ſtring is called G; it is a fifth above the firſt, and its length is equal to two thirds of the firſt; and ſo forth.

It muſt be remarked, that ſeven names, or letters, are given to all the tones; viz. C, D, E, F, G, A and B to the firſt ſeven; then the ſame names or letters are repeated in the ſame order for the next ſeven, and might again be repeated for a third ſet, a fourth ſet, &c.

By a cloſer inſpection, it may be perceived, that the fractions, which expreſs the lengths of the ſtrings, are quite different from each other for the firſt ſeven notes only; but after that they come again in the ſame order; excepting only that for the next ſeven tones the fractions are the halves of the former reſpectively; for inſtance, the length of the ſecond C is $\frac{1}{2}$; viz. the half of the firſt C; the length of *g* is $\frac{2}{6}$ths; viz. the half of G, which is $\frac{2}{3}$ds, &c. Farther, the third ſet of ſeven ſtrings are the halves of the ſecond ſet, or the quarters of the firſt; and ſo on. The numerical names go on

increaſing

increaſing progreſſively; for they only ſhew the diſtance of each tone from the firſt; thus *c* is ſaid to be an *octave* to C; *g* is ſaid to be a *twelfth* to C, &c.

It is therefore evident, that ſeven are the principal tones of the muſical ſcale. The next ſeven are ſaid to be the *octaves* of the firſt; the next ſeven to thoſe are ſaid to be the *double octaves* to the firſt ſeven, &c. Therefore with reſpect to the peculiar nature of each tone, we need only examine one octave, viz. the firſt ſet of ſeven tones, together with the firſt tone of the next ſet.

The fractions of the table expreſs the proportional lengths of the ſtrings with reſpect to the firſt; but if the length of each ſtring be compared with the ſtring next to it, then it will appear that the intervals are not equal throughout the octave; but that there are three ſorts of interval. Thus C (always meaning the ſtring which expreſſes C, and the ſame of the reſt) is to D as 9 to 8. D is to E as 10 to 9*. E is to F as 16 to 15. F is to G as 9 to 8. G is to A, as 10 to 9. A is to B as 9 to 8; and laſtly, B is to the C, next to it, as 16

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* In order to make the above-mentioned compariſon, the fractions muſt be reduced to a common denominator; then the ratio of their numerators muſt be expreſſed in the loweſt integral terms; thus $\frac{8}{9}$ and $\frac{4}{5}$ reduced to a common denominator, become $\frac{40}{45}$ and $\frac{36}{45}$; then 40 is to 36, as 10 is to 9.

to 15. The intervals farther on are equal to the former, and come in the ſame order.

By inſpecting the preceding paragraph, it will appear that thoſe intervals are of three ſorts, viz. the interval of 9 to 8, the interval of 10 to 9, and the interval of 16 to 15. The firſt of thoſe intervals has been called a *major tone*; the ſecond has been called a *minor tone*; and the laſt has been called an *hemitone* *.

The intervals which form an octave, are diſpoſed in the following order, viz. major tone minor tone, hemitone, major tone, minor tone, major tone, and hemitone; which may be expreſſed by their initials, as in the fourth column of the table in p. 372, viz. T, *t*, H, T, *t*, T, H. Whence it appears, that a fifth, or the interval between C and G, contains two major tones, one minor tone, and an hemitone; alſo a fourth, or the interval between C and F, contains a major tone, a minor tone, and an hemitone, &c.

If it be aſked why are the intervals diſpoſed in the above-mentioned order, and why is C conſidered as the firſt or fundamental note? The anſwer is, that repeated experience has ſhewn, that this order produces a pleaſing muſical melody, and that the C is called the fundamental, or key-note, or the firſt

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* The difference between a major and a minor tone, viz. between $\frac{9}{8}$ and $\frac{10}{9}$, which is the interval of 81 to 80, has been called a *comma*.

of

of that order of intervals; becauſe the melody generally begins, and almoſt always ends with that note; beſides, the rules of compoſition, and the arrangement of the various periods of the melody, always have a reference to that key-note.

In the table of page 372, there is, however, another tone, which may be taken for the principal or key note, and that is A; but the intervals in the octave, from A to *a*, are in the following order, viz. T, H, T, *t*, H, T, *t*, which order differs from the other, principally in its having the interval of the third, and the interval of the ſixth, ſmaller than in the other order; hence this order is called the *flat mood*, or the key of A with a flat third; whereas the other is called the *ſharp mood*, or the key of C with a ſharp third.

Nature ſeems not to admit of any other order of intervals fit for muſic; therefore, in the natural ſcale, as expreſſed in page 372, no other note may be taken for the principal or key-note; ſo that no piece of muſic could be written in any other key beſides C or A. But the ingenuity of muſicians has contrived to multiply the key notes, or rather to render every tone capable of being conſidered as the key note of a ſharp as well as of a flat mood; and this object has been accompliſhed by the interpoſition of certain intermediate tones between thoſe of the natural ſcale, which are to be uſed occaſionally, and which have no particular name or letter; but derive their appellations from the

the neighbouring principal notes; thus a certain ſound, interpoſed between C and D, is called either C ſharp, or D flat: another interpoſed between D and E, is called either D ſharp, or E flat; and ſo of the reſt. It muſt be remarked, however, that between E and F, as alſo between B and C, no other ſound is interpoſed, becauſe the intervals between thoſe notes are already very ſmall, there being only an hemitone between each pair.

The nature and the uſe of thoſe intermediate ſounds, which are commonly called *flats* and *ſharps*, will appear from the following example and explanation.

If, inſtead of C, a perſon wiſhed to make F the key note; then the proper order of intervals either for a flat, or for a ſharp mood, muſt take its commencement from F.—Suppoſe it be required to be a ſharp mood, in which caſe the intervals muſt be T, *t*, H, T, *t*, T, H. Now, by obſerving the table in page 372, it will be found that there is, as it ought to be, a major tone between F and G, a minor tone between G and A; but between A and B there is a major tone; whereas there ſhould be an hemitone; therefore in order to remedy this defect, another ſtring is interpoſed between A and B, of ſuch a length as may expreſs a proper fourth to F; and this intermediate ſound is called B flat, or A ſharp: then between this B flat, and the next C, there is a major tone, which is right; and ſo are likewiſe the following intervals. So that when

when F is to be reckoned the key note, we muſt then uſe B flat inſtead of B natural.

After the ſame manner it may be eaſily ſhewn that when any of the other notes is taken for the key note, there needs be interpoſed flats or ſharps between ſome of the other natural or primitive ſounds, &c.

In ſhort, by the interpoſition of one ſound between any two contiguous tones of the natural octave, except between E and F, as alſo between B and C, the whole octave is cauſed to contain 12 intervals; and by this means every one of thoſe 12 ſounds may be taken for the key note of a ſharp or a flat mood, and is called accordingly; for inſtance, the key of D with a ſharp, or with a flat, third; the key of E with a ſharp, or with a flat, third; the key of E flat, with a ſharp third, or the key of E flat, with a flat third; and ſo of the reſt.

Yet this diſpoſition of tones, both principal and intermediate, is attended with a remarkable imperfection, which may be palliated, but cannot be entirely removed. — The nature of this imperfection will be ſhewn in the ſequel; but previouſly to it, ſomething muſt be ſaid with reſpect to the notation of the various muſical ſounds.

The whole range of muſical ſounds, comprehending all thoſe which may be expreſſed by human voices, as alſo by the muſical inſtruments that are moſtly in uſe, conſiſts of about ſeven or eight

octaves;

octaves; yet muſicians can expreſs every one of thoſe ſounds by placing certain ſpots, marks, or notes, upon, and adjoining, five parallel lines; and, in fact, muſic paper is ruled with ſuch zones of parallel lines.

A mark or note, placed upon one of thoſe lines, denotes a certain tone; for inſtance C, a mark placed in the ſpace which is between that line and the next above, denotes the next note to that, viz. D; a mark on the next line above, denotes E; and ſo forth. The intermediate ſounds, or the flats and ſharps, are denoted by auxiliary marks, viz. ※ denotes a ſharp, and *b* denotes a flat; thus ※ prefixed to the note of D, means the ſound intermediate between D and E; and *b* prefixed to the note of E, means the ſame ſound, viz. the ſound intermediate between D and E, &c.

The form of the notes, viz. whether the mark is entirely black, or open like an o, or having a tail annexed to it, has nothing to do with reſpect to the particular ſound. That diverſity of form indicates the duration only of the ſounds; or what is called the *time*.

By inſpecting any one of the zones in fig. 6. Plate XIV. it will be perceived that, upon the uſual five lines of muſic, no more than eleven different notes can be marked, viz. one upon each line, one upon each of the four ſpaces between thoſe lines, one above the upper line, and one below the firſt

line;

line: at preſent, indeed, the notation is extended conſiderably above and below the five lines, and that by means of auxiliary little lines, as in fig. 7. Plate XIV.; yet this laſt-mentioned method is by no means ſufficient to expreſs the whole range of muſical ſounds. Formerly, however, they uſed only the eleven notes of fig. 6 *. Now, in order to expreſs the higher or lower tones, the names and ſignification of the notes are altered, and this alteration is indicated by a certain mark, called *cliff*, which is always placed at the beginning of a piece of muſic, and likewiſe wherever the value of the notes is required to be altered.

There are ſeven of thoſe cliffs. (See fig. 8. Plate XIV.) They are of three different forms, and of three different ſignifications, viz. the firſt two are called cliffs of F, becauſe where they are placed, (viz. on the fourth line and on the third line) there the note of F is ſituated, and the other notes above and below are named accordingly. The four cliffs of the ſecond ſpecies are called cliffs of C, becauſe where they are ſituated, viz. upon four of the five lines, there the C is placed. Of the

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* The ancient maſters of muſic reckoned a good voice for ſinging, whether baſe, or tenor, or treble, &c. that which could expreſs eleven good and pleaſant tones. In fact, very ſeldom a ſinger can go higher or lower, without changing the quality of his voice. Hence eleven principal marks were reckoned ſufficient for muſical notation.

third ſpecies there is but one cliff, which is called the cliff of G, becauſe where that cliff is ſituated, viz. on the ſecond line, there the note of G is placed.—Thoſe cliffs, beſides the ſpecific names, have each a peculiar appellation. The peculiar appellations of thoſe cliffs, together with the names or ſignifications of the notes in each cliff, are clearly exhibited in fig. 6. Plate XIV. wherein the notes, for brevity ſake, are not carried on farther above or below the eleven above-mentioned notes*.—Should the reader be deſirous of learning which note of one cliff correſponds with a certain other note of the other cliffs, fig. 9. Plate XIV. will give him the required information; for in that figure, a note is placed after every one of the ſeven cliffs, and every one of thoſe notes indicates the ſame ſound preciſely; namely, the C, which is expreſſed by placing the third finger upon the fourth or largeſt ſtring of a violin.

Hitherto we have only mentioned the dependance, or rather the ratio that one ſound bears to another; ſo that when one ſound is given, its fifth, or third, or octave, &c. may be eaſily found; but it will be neceſſary to define or determine the firſt, or any one of them, ſince from one being known, all the others may be derived. The conveniency of fingers has eſtabliſhed a certain ſtandard, which is

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[*] At preſent, however, the baritone cliff, and the half ſoprano cliff, are ſeldom, if ever, uſed.

adopted by moſt muſicians in this country; is uſed in concerts, as alſo at the opera houſe, play houſes, &c. It is called the *concert pitch*; and this ſound is expreſſed by a ſmall inſtrument, which is conveyed from place to place by thoſe perſons who tune organs, harpſichords, &c. It is a ſteel inſtrument, which when ſtruck ſounds a certain note. See fig. 11. Plate XIV. or elſe a little ſort of flute, which ſounds that certain note. Thoſe *tuning forks*, or *tuning pipes*, (for ſo they are called) are tuned all alike, after a pattern one, which is kept in reſerve by the makers; and indeed, notwithſtanding the wear and alteration by heat and cold, thoſe tuning forks are in general pretty much of the ſame pitch. According to that pitch, the C, which follows the cliffs in fig. 9. performs about 513 vibrations in one ſound.

Fig. 12. of Plate XIV. exhibits in one view all the particulars which may be of uſe with reſpect to an octave of tones, hemitones, &c. It conſiſts of 6 horizontal rows. The firſt row contains the 13 notes of an octave expreſſed in the baſe cliff. The ſecond row ſhews the ratio of the ſtring which expreſſes each ſound, with reſpect to the firſt. The third row expreſſes the lengths of the various ſtrings, (which muſt be equal in all other reſpects) in numbers of equal parts, of which 3600 are equal to the length of the firſt ſtring. The fourth row expreſſes the actual number of vibrations performed in one ſecond by each ſound, according

cording to the concert pitch *. The fifth row contains the literal names; and the ſixth row contains the numerical names of the ſounds, when C is the firſt, or key, note.

Hitherto we have only ſpoken of the ſucceſſion of ſounds, and have aſſerted that the ſounds only of the ſcale, which is ſtated in page 372, can furniſh a pleaſing

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* Thoſe numbers of the vibrations, &c. have been deduced by calculation, according to the rule in page 362; wherein the reſiſtance of the air is not noticed; hence they probably are a little higher than the truth.

For this purpoſe a braſs harpſichord ſtring was ſuſpended like a pendulum, with a weight of 5 lb. and 14 ounces (viz. 41125 grains) at its extremity. The length of the ſtring was 62 inches, its weight was 22,25 grains. Its ſound, according to the concert pitch, was exactly A, viz. one octave below the A, in fig. 12. By calculation, from thoſe data, it was determined to perform 107 vibrations in one ſecond.

Heat and cold have a conſiderable influence on the pitch of all ſonorous bodies, which ariſes from their being expanded or contracted in their dimenſions, alſo from an alteration of their elaſticity. A ſteel tuning-fork, heated to the degree of boiling water, will ſound a note about a hemitone lower than it will when cooled to the degree of freezing water. The pitch of an organ pipe will be higher in ſummer than in winter; for in that pipe it is the column of air that vibrates; and in the winter time that column of air is denſer, heavier, and of courſe vibrates ſlower, than in ſummer. See Smith's Harmonics, Sect. IX. Schol. to Prop. XVIII.

pleaſing melody, or rather the moſt pleaſing melody. But it is neceſſary to obſerve, that the propriety of ſuch ſounds is ſhewn likewiſe by the agreement, or pleaſing effect, which ariſes from certain two or more of them being expreſſed at the ſame time; and it is remarkable that the like pleaſing effect cannot be produced by any other ſcale of ſounds.

When two ſonorous bodies, that expreſs the ſame note preciſely (in which caſe they are ſaid to be in *uniſon*) are ſounding at the ſame time; the agreement is ſo great, that we can ſeldom perceive whether it be one ſound or two. The next beſt agreement is when any note, and its octave, are ſounded at the ſame time. Next to this is that of any note and its fifth; then that of any note and its third ſharp, and then that of any note and its third flat, or its ſixth, either flat or ſharp.

A perfect accord is that which ariſes from four notes expreſſed at the ſame time, viz. any note, its third ſharp, its fifth, and its octave. The other accords are *imperfect*; and ſome of them are very diſagreeable; yet with certain reſtrictions ſome of them are not only tolerable, but may be introduced with conſiderable effect.

The rules of muſical compoſition, which direct the proper arrangement of accords, and likewiſe ſhew the neceſſary limitations or management of the melody, have been deduced from long and diverſified experience. Upon the whole, they are rather intricate and numerous; but notwithſtanding their multiplicity, the various caſes and combinations of muſical ſounds are far from being all reduced, and ſeem not to be all reducible, to certain and determinate rules. In muſical compoſition, a great deal muſt depend upon the genius of the compoſer; and this genius, or natural diſpoſition, to invent pleaſing melodies, and pleaſing harmony, is what principally diſtinguiſhes one compoſer from another. It is the gift of nature; it may be guided, but not given, by art.

It has been ſaid above, that the diſpoſition of tones and hemi-tones, ſuch as is exhibited in fig. 12. Plate XIV. is attended with a remarkable imperfection, which may be palliated, but cannot be entirely removed.—The nature of this imperfection will be eaſily manifeſted by means of an example.

The proportional, as well as the proper lengths of the ſtrings, which expreſs the 2d, 3d, 4th, 5th, &c. of C; viz. when C is taken for the key note, are expreſſed in fig. 12. But ſuppoſe it be required to make, not C, but D, the key note; then A, which was the ſixth of C, does now become the 5th of the key note D; and therefore its length muſt be two-thirds of the length of D. Now, in the table, the length of D is 3200 equal parts, and that of A is 2160 ſuch parts; but 2160 is not equal to two-thirds of 3200 (for $\frac{2}{3}$ of 3200, are 2133,33, &c.); therefore the A in the ſcale, which

which is a proper ſixth to C, is an imperfect 5th to D; nor can this deficiency be ſupplied by the interpoſition of another ſtring between A and A ſharp; becauſe that other ſtring, though a perfect fifth to D, would be an imperfect fourth, when E is taken for the key note, or it would be an improper 3d, when F is taken for the key note, &c. And if ſo many ſtrings were interpoſed between A and A ſharp, as to ſupply all thoſe deficiencies, the complication and multiplicity of ſounds would be endleſs; for what has been ſaid of A may, with equal propriety, be ſaid of every other ſound of the octave.

The only expedient which is at preſent practiſed for the purpoſe of palliating the above-mentioned imperfection, is to tune the A not ſo high, or to make the length of that ſtring not ſo long as 2160 parts, nor ſo ſhort as 2133,3, by which means that A is rendered an imperfect ſixth to C, and an imperfect fifth to D; or the imperfection is divided, which renders it tolerable in both caſes, otherwiſe it would be very pleaſant in one caſe, but intolerable in the other. The ſame thing is done with reſpect to all the other ſounds of the octave; viz. they are made to deviate a little from thoſe proper pitches, or from the lengths, which are expreſſed in fig. 12. for the purpoſe of rendering them tolerable when one note or another is taken for the key note. This deviation from the proper lengths, or from the proper pitches, is called the *temperament* *of muſical inſtruments, or of the muſical ſcale*; and is uſed in tuning all thoſe inſtruments which have fixed notes, as the harpſichord, organ, &c. And even with other inſtruments, and with the voice in ſinging, a certain temperament is uſed, both from imitation and from neceſſity *.

It muſt be obſerved, with reſpect to this temperament, that if the imperfections be divided equally, viz. in ſuch a manner as to render the effect the ſame, whether one or another of the 12 ſounds of the octave be conſidered as the key note; then that effect would not be pleaſant; therefore the practice is to divide the imperfections, but to divide them *unequally*; viz. ſo as to render the ſecond, third, fourth, fifth, &c. of ſome key notes, in which moſt pieces of muſic are written, leſs imperfect than others.

An equal temperament, therefore, is impracticable; and it is impoſſible to fix the limits of an unequal one, or ſuch as may be commonly uſed; for almoſt every tuner of inſtruments uſes a temperament a little different from the reſt, of which he judges by his hearing only; and ſome capital performers ſometimes have their inſtruments tuned with a peculiar temperament, for the purpoſe of

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* For the nature and limits of the temperament of muſical inſtruments, ſee my paper on the ſubject in the 78th vol. of the Philoſophical Tranſactions.

giving a greater effect to their particular compoſitions *.

We ſhall, laſtly, conclude this long chapter with ſome remarks concerning the effects which are attributed to muſical ſounds. Of thoſe effects there are ſome which are true and acknowledged; whilſt others are leſs conſpicuous, or doubtful, and perhaps abſolutely chimerical.

Single ſounds, or a ſucceſſion of ſounds, are pleaſant or unpleaſant in various degrees. The ſingle ſounds, in order to be pleaſant, muſt be uniform, neither too loud nor too ſoft, and muſt be as ſimple as poſſible. A regular ſwell and decay in the ſtrength of the ſound is pleaſing in certain caſes; but it is impoſſible to define the quantity of thoſe qualities.

The various tones of a natural voice, or of an inſtrument, ſhould be of one quality; whereas they frequently ſeem to belong to different voices, or to different inſtruments †.

It

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* I have a ſet of tuning-forks, for all the 13 ſounds of an octave, which were tuned by one of the beſt piano-forte makers in town, according to his temperament; but on comparing them with inſtruments recently tuned by other perſons, I find that they very ſeldom, if ever, agree perfectly together.

† The ſtrings of piano-fortes, harpſichords, &c. were they all of the ſame thickneſs, could not conveniently be made of the proper lengths; therefore, by making them of different

It is impoſſible to ſay whence ariſes the pleaſure which is communicated by certain ſucceſſions of ſounds. There are certain periods in muſical melody which excite peculiar ſenſations more or leſs pleaſing, and produce different ſenſations of pleaſure or diſpleaſure, upon different perſons. Thoſe ſenſations cannot be expreſſed or defined.

The agreement or diſagreement of two or more ſounds, expreſſed at the ſame time, ſeems, upon the whole, to ariſe from the more or leſs frequent coincidence of the vibrations. Thus any tone and its octave, agree better than the ſame tone and its fifth, the latter better than the ſame tone and its third, &c. viz, the compound ſound is ſmoother, and approaches nearer to the nature of a ſingle ſound in the firſt caſe; leſs in the ſecond; ſtill leſs in the third, &c. And in fact, in the firſt caſe there is a coincidence of vibrations at every ſecond vibration of the grave tone; the coincidence is not ſo frequent in the ſecond caſe; ſtill leſs in the third, and ſo on; yet the more or leſs pleaſant or unplea-

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different ſizes, and by ſtretching them differently, their lengths are ſuited to the commodious ſize of the inſtrument. Now the great object in adjuſting the ſizes and lengths of ſuch ſtrings, is to contrive that each ſtring be ſtretched by a force proportionate to its thickneſs and length; otherwiſe the inſtrument will not have a uniform voice.— Few makers of ſuch inſtruments pay ſufficient attention to this particular.

ſant effect, cannot ariſe entirely from that more or leſs frequent coincidence; for (beſides other reaſons which, to avoid prolixity, ſhall not be mentioned here) in the firſt place, a ſucceſſion of thirds or of ſixths is much more pleaſant to the ear than a ſucceſſion of fifths; and, in the ſecond place, the introduction of a diſcord in certain accords, is not only tolerable, but very pleaſing. The caſes in which diſcords may be introduced, have been found by experience, and are ſpecified amongſt the practical rules of muſical compoſition, which do not belong to this treatiſe.

It has been ſaid above, that ſeldom, if ever, a ſounding body expreſſes a ſingle ſound; and that ſuch ſounding bodies are uſed in muſic as expreſs the ſimpleſt ſounds. But even amongſt thoſe, ſome ſingular productions of ſecondary ſounds have been remarked, and the principal facts are as follows:

If a large ſtring of a muſical inſtrument be ſounded, or, in ſhort, if a pretty deep and rather ſtrong ſound be continued for a little time, there will be heard at the ſame time two other ſounds; namely, the 12th and the 17th of the original ſound. For inſtance, if the loweſt C in the baſe cliff be ſounded, you will hear the ſecond G and the third E of the ſcale above.

It was diſcovered by Tartini, at Ancona, in the year 1713, that if of the three notes which form the perfect accord of 3d, 5th, and octave, (as for inſtance C, E, and G; or G, B, and D, &c.) two be ſounded at the ſame time, a third ſound will be heard, viz. a fundamental note *.

The various caſes of this ſort are ſhewn in fig. 10. Plate XIV. where the open notes are thoſe which muſt be ſounded (and here it is to be obſerved, that they muſt be ſounded perfect, viz. without temperament), and the black note is the ſound which is heard. The firſt caſe is evidently the reverſe of that which is mentioned in the paragraph laſt but one. In the laſt caſe, the note which is heard is in uniſon with one of thoſe which is ſounded; but it may be diſtinguiſhed by its being a ſound of different quality.

The true reaſon of thoſe phenomena is not known; nor ſhall I detain my reader with any account of the inſufficient hypotheſes that have been offered for their explanation. Certain it ſeems, that the third ſound is not produced by the undeſigned communication of the vibrations to ſome other ſtring or pipe of the inſtrument; for if you take a violin, and ſound at the ſame time C on the largeſt ſtring, and A on the next, you will alſo hear an F, which is a 12th below the C, and which cannot be expreſſed upon any ſtring of the violin; G being the loweſt note of that inſtrument.

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* See Tartini's Treatiſe, *della vera ſcienza dell' Armonia.*

Frequent mention is made by the ancient writers, as alſo by modern enthuſiaſts, of the wonderful effects of muſic on the paſſions. Anger, compaſſion, love, melancholy, cheerfulneſs, &c. may in ſome meaſure be excited by muſic; but the concurrence of other circumſtances, the exaggeration of the accounts, and the various ſenſibility of individuals, will not allow us to ſettle the ſtandard of credibility upon any ſure foundation. The ancients, under the name of muſic, comprehended poetry and dancing; and we may eaſily believe that fine poetry ſet to muſic in a ſimple melody, and perhaps accompanied with dancing, or with actions, may have had conſiderable effect on the fancies and affections of different perſons, eſpecially of thoſe to whom it arrived new.

With reſpect to the effects of modern muſic, which is undoubtedly more refined than the mere muſic of the ancients, moſt, and perhaps all, of my readers are able to judge for themſelves.

Amongſt the extraordinary effects that have been aſcribed to muſic, its affording a cure for the poiſon of the Tarantula ſpider, has been ſo frequently aſſerted, that it would appear improper to leave the ſtory quite unnoticed in this chapter.

In the ſouthern part of Italy, eſpecially in the ſouth of Naples and in Sicily, ſometimes perſons, almoſt always of a low condition, are bit by a largiſh

largiſh ſort of ſpider, called *tarantula*. At certain periods of the year the perſon that has been once ſo bit, aſſerts to feel a pain about the part bit, which is accompanied with dejection of ſpirits, ſallowneſs, &c. If ſprightly muſic be played (and a certain jig, called the *tarantella*, is generally played on ſuch occaſions) the patient gets up, and begins to dance with irregular geſtures; the quickneſs of his movements generally increaſes to a certain degree; and the dance continues ſometimes without intermiſſion for hours. At laſt the patient, fatigued and exhauſted, throws himſelf down on the floor, or on a chair, or a bed, &c. to recruit his ſtrength; and the fit is over for that time.—The remarkable part of the ſtory is, that this exertion of dancing, &c. cannot be done without muſic.

In the firſt place, it is very doubtful whether the ſpider is at all poiſonous, or whether it has any ſhare at all in the production of the pretended illneſs.

The diſorder, probably a nervous or hyſterical affection, may ariſe from other cauſes, eſpecially in a pretty warm climate. And the violent agitation of the patient, accompanied with perſpiration, &c. may, very likely, relieve him or her (for the tarantula bites women as well as men).

The pretended indiſpenſable aid of muſic, the long continuance of the dance, the ſtrange geſtures,

tures, and ſeveral odd fancies, which ſuch patients are ſuppoſed to have, are, in all probability, dictated by prejudice, by the love of ſingularity, or by the deſire of exciting aſtoniſhment in the minds of the ſpectators, who are always numerous on ſuch occaſions.

CHAPTER XIII.

A GENERAL VIEW OF THE PRINCIPAL USES OF THE ATMOSPHERE; WHEREIN THE NATURE OF RAIN AND EVAPORATION WILL BE NOTICED.

THE aërial fluid, which ſurrounds the earth, and whatever exiſts thereon, is unnoticed by the vulgar, amongſt whom the words *air* and *nothing* are almoſt ſynonimous; it is conſidered as a ſuperfluous appendage by the ſuperficial obſerver; but the deepeſt reſearches of the moſt enlightened philoſophers, acknowledge the infinite wiſdom of nature, in the creation of a fluid moſt indiſpenſably neceſſary for the maintenance of animal and vegetable life; for the diſperſion of light; for the communication of ſound; for the abſorption of water from certain places, and the diſperſion of the ſame fluid over other places; for giving motion to a variety of uſeful machines, &c.

There is not one of the properties of the air, nor one of its movements, however trifling or irregular may at firſt ſight appear, which, when duly conſidered, will be found to be uſeleſs or defective. Were the air either lighter or heavier; had it a different degree of elaſticity, than it does now poſſeſs,

poſſeſs, were its other properties at all altered, the organiſm of the terraqueous globe would be deranged, and perhaps utterly deſtroyed.

The ſame incomprehenſible wiſdom that has arranged all the parts of the univerſal frame in due weights and proportions, may undoubtedly fit them to a different ſort of atmoſphere by a ſuitable alteration of the whole ſtate of things; but our very limited comprehenſion, not being able to conceive how ſuch an alteration could be made for the better, only finds ample reaſon for ſatisfaction, admiration, and wonder, in the inveſtigation of the properties of the exiſting atmoſphere.

After having admired the general order, and the providential wiſdom of nature, it will be neceſſary to examine, with patient toil, what more immediately concerns us, viz. the particular uſes of the atmoſphere, at leaſt as far as may be inſerted in this place; for we muſt neceſſarily reſerve the chemical properties of air, and its connection with light, heat, and electricity, for the ſubſequent parts of this work.

It is in conſequence of the weight and elaſticity of the air, that animals reſpire with freedom, and that the operations of ſucking, pumping, &c. are performed.

The thorax, or that part of the human body which is ſurrounded by the ſpine or back bone, the ribs, the ſternum or breaſt bone, and the diaphragm, is almoſt entirely occupied by the lungs, which

which conſiſt of an immenſe number of veſicles; whoſe cavities communicate with certain ducts; and thoſe ducts, with others of a larger ſize, which at laſt communicate with a large one, called the *wind pipe*, the aperture of which is in the mouth, at the back or root of the tongue.

The air, unleſs we keep both the mouth and the noſtrils cloſed, communicates with the inſide ſurface of the lungs; that is, of its innumerable veſicles, and with the outſide of the thorax or cheſt. If we enlarge the cheſt, the weight of the atmoſphere drives a quantity of air in our lungs, which is called *an inſpiration*; and if we contract our cheſt, a quantity of air is expelled from it, which is called *an expiration.*

The enlargement of the cheſt is occaſioned by an elevation of the ribs, by a ſmall motion of the ſternum, and by a ſuitable movement of the diaphragm; but the action of each part cannot be underſtood without a particular anatomical deſcription, which does not belong to this treatiſe.

The freedom of reſpiration in a ſound animal body, depends on the equal preſſure of the atmoſphere, both on the inſide ſurface of the lungs, and on the outſide of the body. In fact, if we keep both mouth and noſtrils accurately cloſed, we can neither contract nor expand our cheſt; excepting, indeed, in a ſmall degree; for the quantity of air which always remains within the lungs, may

may be a little rarefied, or compreſſed, by the exertion of our muſcles.

A man uſually performs about twelve inſpirations, and as many expirations in a minute; but reſpiration may be quickened by various cauſes, as by agitation of the body or mind, by heat, by a rarefied or vitiated atmoſphere, and by diſeaſes. Infants breathe quicker.

In general, a full grown perſon takes in between 20 and 30 cubic inches of air at every inſpiration, and expels about the ſame quantity at every expiration, but a great deal of air does always remain in the lungs. In a forced or violent inſpiration or expiration, a double quantity of air, viz. about 50 cubic inches of air, may be taken in or expelled, and even then a conſiderable quantity of air remains in the lungs, beſides what is contained in the mouth, wind pipe, &c. for the capacity of the lungs of a man, may at a mean be reckoned equal to about two cubic feet.

The operation of ſucking, in general, conſiſts in removing the preſſure of the atmoſphere from a certain part of the ſurface of a fluid, whilſt that preſſure is at liberty to act on ſome other part of the ſurface of the ſame fluid, in conſequence of which the fluid is forced to aſcend where the preſſure has been removed or diminiſhed.

If a man apply his mouth to the aperture of a bottle full of liquor, and ſtanding ſtraight up, he will not be able to ſuck any liquor out of it; but

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if a hole be opened at the bottom of the bottle, and that bottle be ſet in a baſon full of liquor, then the liquor may be ſucked out of it. And the ſame effect will take place if an open tube be ſet with one end in water, and a man apply his mouth to the other end, and ſucks. The mechanical part of the operation is as follows:—By enlarging his cheſt, the man rarefies the air, and, of courſe, diminiſhes its preſſure on the liquor, which is immediately under the tube; in conſequence of which the preſſure of the atmoſphere on the ſurface of the ſurrounding liquor, forces the liquor to aſcend into the tube. (See the experiment, which is deſcribed in page 205.)

In the operation of ſucking, after the manner of children, the rarefaction is produced in the fore part of the mouth; viz. the tongue is applied ſo as to fill up the ſpace between the lips and the nipple, or pipe which conveys the milk or other liquor; then the tongue is drawn backwards, whilſt the lips are laterally preſſed againſt it, by which means a little vacuum is formed before it, and the liquor is forced into that vacuum by the preſſure of the atmoſphere upon its external ſurface, or upon the ſurface of the bag which contains it.

If an empty veſſel, having one aperture, be applied with its aperture to the lips, and the abovementioned operation of ſucking be performed, the veſſel, if not too heavy, will remain attached to the lips, and that for the ſame reaſon.

It is for the ſame reaſon, that ſnails remain attached to ſolids, that limpets adhere very firmly to rocks, that the ſea polypus holds with great force whatever it faſtens its claws to, and that ſome inſects ſuſpend themſelves to ſolids; for though not performed with the mouth, the principle of the operation is exactly the ſame, viz. a ſoft membrane is applied to the ſolid, then the middle part of that ſurface is withdrawn a little way, ſo as to form a vacuum, or at leaſt a rarefaction of the air between the centre of the ſoft membrane and the ſolid, in conſequence of which the parts of the membrane which ſurround that ſpot, are by the gravity of the atmoſphere preſſed againſt the ſolid, and the latter is preſſed againſt the former; hence the adheſion takes place.

Leather ſuckers, which act preciſely upon the ſame principle, are not unfrequently ſeen in the hands of boys about the ſtreets of London. A circular piece of thick leather, about two inches in diameter, has a ſtring, faſtened to its centre. The leather being previouſly well ſoaked in water, is applied flat and cloſe to the ſmooth ſurface of a ſtone. The interpoſition of a little water promotes the adheſion. Then the boy pulls up the ſtring, and the ſtone, if not too heavy, comes up adhering to the leather.

The claws of the polypus are furniſhed with a great many ſuckers of the like nature. The limpet forms one ſucker of its whole body, and the ſame thing,

thing, with little variation, is done by various other animals, eſpecially of the inſect tribe.

The action of the glaſs cup, which is made to adhere to the fleſh, for the purpoſe of bleeding, depends upon the ſame principle; excepting that the air, within the glaſs cup, is rarefied by means of heat, or by means of a ſmall exhauſting engine.

It is hardly needful to add, that the limpet could not adhere to the rock, nor could the leather ſucker act, or, in ſhort, that none of thoſe ſucking operations could take place, *in vacuo*.

The principal advantage which is derived from the vibratory movement of the air, is the propagation of ſound, which could not be accompliſhed by other means; for though ſounds are conveyed by ſeveral other bodies better than by air; yet in common affairs other bodies are neither to be found, nor can they be applied between the ſounding bodies and our ears: whereas the air, by ſurrounding the whole earth, and whatever exiſts upon it, is always ready to convey ſounds of any ſort, and in every direction.

The progreſſive motion of the air is alſo of immenſe and indiſpenſable uſe. The winds, ſo general, ſo frequent, and ſo various, beſides the more obvious effects of driving ſhips, windmills, &c. preſerve, by mixing, the neceſſary purity of the atmoſphere. The air is contaminated by animal reſpiration, by fermentation, and putrefaction of animal and vegetable ſubſtances, as alſo by other proceſſes;

proceſſes; on the other hand it is purified by vegetation in certain circumſtances, by agitation amongſt aqueous particles, and probably by other means. Now it is owing to the winds that the impure portions of the atmoſphere are mixed with the more purified parts of it; and that a proper mean is preſerved. The winds likewiſe drive away vapours, clouds, fogs, and miſts, from thoſe parts in which they are copiouſly formed, to others which are in want of moiſture; and thus the whole ſurface of the world is ſupplied with water. But it will be neceſſary to take a more particular notice of what relates to evaporation and rain.

When water is left expoſed to the ambient air, the quantity of it will be gradually diminiſhed, and after a certain time, the whole of it will diſappear. The water in this operation is reduced into an elaſtic fluid, and is gradually diſperſed throughout the air.

If a ſmall drop of water be placed in a large glaſs bottle full of pretty dry air, the drop of water will diſappear after a certain time, eſpecially if the bottle be placed in a warm place. And if afterwards the ſame bottle be cooled, the water will thereby be ſeparated from the air, and may be ſeen adhering to the inſide ſurface of the bottle.

Heat promotes, and cold retards, evaporation; but even a piece of ice has been found to evaporate, and to be diminiſhed in weight, whilſt the atmoſphere is actually in a freezing ſtate.

Winds, or agitation, promotes evaporation.

If a quantity of water be placed in vacuo, viz. it be placed under the receiver of an air pump, in the common temperature of the atmoſphere, and the air be exhauſted, a very ſmall portion of the water will expand itſelf through the receiver, after which the quantity of water will remain unaltered. If the pumping be continued, the water will be diminiſhed a little more; for as part of the ſteam is extracted from the receiver, a little more ſteam is ſeparated from the water; but, upon the whole, the water will by this means be diminiſhed in quantity very little indeed. On re-admitting the air into the receiver, the above-mentioned vapour is again condenſed almoſt entirely into water.—Heat promotes the evaporation in vacuo.

Water then may exiſt in air; 1ſt, in an inviſible ſtate, which is the caſe when the diſſolving power of air is conſiderable; 2dly, in a ſtate of incipient ſeparation, in which caſe it forms *clouds*, *miſts*, or *fogs*; 3dly, and laſtly, in a ſtate of actual ſeparation, in which caſe it forms either *rain*, properly ſo called, or *ſnow*, or *hail*.

Clouds are thoſe well known aſſemblages of vapours that float in the atmoſphere; have different degrees of opacity, which ariſes from their extent and denſity; and generally have pretty well defined boundaries. Their height above the ſurface of the earth (I mean not above the mountains) is various, but hardly ever exceeds a mile or a mile and a half.

In hot weather, or hot climates, the clouds, being more rarefied, are lighter, and aſcend much higher than they do in colder climates, or colder weather: and indeed, in cold weather the clouds frequently touch the very ſurface of the earth; for a fog may with propriety be called a cloud cloſe to the ground.

A *miſt* is a very indefinite word. It means an incipient formation of clouds, or hazineſs; and it often denotes a very ſmall rain, or a depoſition of water in particles ſo ſmall as not to be viſible ſingly.

The *ſnow* is formed when the atmoſphere is ſo cold as to freeze the particles of rain as ſoon as they are formed, and the adherence of ſeveral of thoſe particles to each other, which meet and cling to each other as they deſcend through the air, forms the uſual fleeces of ſnow, which are larger, (ſince they are longer in deſcending, and have a greater opportunity of meeting) when the clouds are higher than when they are lower.

The *hail* differs from ſnow in its conſiſting or much more ſolid, and much more defined pieces or congealed water. It is ſuppoſed that the water, already formed into conſiderable drops, is driven and detained a conſiderable time through a cold region of the atmoſphere, by the wind, which almoſt always accompanies a fall of hail. But the globes of ice, or *hail-ſtones*, in a fall of hail, ſometimes far exceed the uſual ſize of the drops of of rain*; which ſhews that by the action of the wind, the congealed particles muſt be forced to adhere to each other; and, in fact, though the ſmall hail-ſtones are more uniformly ſolid and globular, the large ones almoſt always conſiſt of a harder nucleus, which is ſurrounded by a ſofter ſubſtance, and ſometimes by various diſtinct pieces of ice, juſt agglutinated. Their ſhape is ſeldom perfectly globular.

If a veſſel of an uniform ſhape, and full of water, be expoſed to the ambient air, and the decreaſe of water in it be meaſured at the end of every day, or month, or year, or, in ſhort, of any given period, the evaporation which has taken place through that period may be aſcertained; and it is generally expreſſed by the number of inches and tenths: thus, if it be ſaid that the evaporation of a certain pond in one month be 10 inches, the meaning is, that 10 inches depth of water are evaporated in one month; or, that if the water which has been evaporated from it in one month might be collected and placed in a

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[*] Accounts of hail-ſtones of a very large ſize may be met with in almoſt all the works of natural philoſophy, in ſeveral periodical works, in accounts of voyages, &c. I have been aſſured by creditable eye-witneſſes, that in the iſland of Sicily hail-ſtones have ſometimes meaſured more than three inches in circumference. Dr. Halley gives an account of hail-ſtones that weighed 5 ounces each. It is no wonder then that falls of hail ſometimes demoliſh glaſſes, kill ſeveral animals, and deſtroy fruit, grain, &c.

veſſel with ſtraight up ſides, and having an horizontal ſurface equal to the ſurface of the pond, the collected water would fill 10 inches depth of that veſſel.

If a veſſel for meaſuring the evaporation be left long expoſed, the ſurface of the water will deſcend a conſiderable way below the edge of it, in which caſe the ſubſequent evaporation would be retarded. This indeed might be remedied by the addition of certain quantities of water at ſtated times; but there is another inconvenience attending it, which is, that inſects, duſt, &c. fall in it, and thicken or cover the water. Therefore, the beſt way is to note the evaporation either every day, or whenever it may be convenient, but to clean the veſſel, and to change the water in it at ſhort intervals; for inſtance, once a week at leaſt. A veſſel fit for ſuch purpoſe ought to have an aperture not leſs than 8 or 10 inches in diameter.

The quantity of evaporation from the ſurface of the ſea or of the land, has been eſtimated in certain places only by a few ſcientific perſons; but their eſtimates are ſeldom to be depended upon. General deductions, for extenſive tracts, from partial, ſmall, and ſometimes equivocal, experiments, cannot afford much ſatisfaction, eſpecially when the reſults of the experiments diſagree from each other.

The quantity of evaporation is various in different ſpots. The ſurface of water furniſhes upon the whole the greateſt quantity of vapour; the land

land more or leſs, according as it is marſhy or rocky, or covered with vegetation, &c.

In hot climates, the evaporation is incomparably greater than in thoſe which are colder. The evaporation from places that are much expoſed to the wind and the ſun, is likewiſe greater than from other places.

It was obſerved in London, by Dr. Halley, that the evaporation of water, ſituated in a room, out of the influence of the ſun and of the wind, amounted, in one year, to 8 inches. It was his opinion alſo, that by the influence of the wind, the quantity of evaporation would have been trebled, and that this again would have been doubled by the influence of the ſun. Upon the whole, he reckons the annual quantity of evaporation for London, at 48 inches[*].—Probably too great.

Dr. Hales eſtimates the annual evaporation from the ſurface of the earth only in England at 6,66 inches[†].

Dr. Dobſon deduced from a mean of accurate experiments made by himſelf during four years, that the annual evaporation from the ſurface of water at Liverpool, amounts to 36,78 inches[‡].

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[*] Phil. Tranſ. N. 212.

[†] Veg. Stat: vol. I.

[‡] Phil. Tranſ. vol. 67th, for 1777. The quantity of evaporation for each of the four years, was as follows: 1772. 35,95 inches; 1773. 34,59 inches; 1774, 36,64 inches; 1775. 39,96 inches.

It has been calculated, that in one ſummer's day, about 5280 millions of tuns of water, are probably evaporated from the ſurface of the Mediterranean*. It has alſo been calculated (omitting the great uncertainty to which ſuch calculations are liable) that all the rivers, or at leaſt the nine principal rivers, which diſcharge their waters into the Mediterranean, do not furniſh more than 1827 millions of tuns of water per day †. The deficiency is undoubtedly ſupplied by the rain, which falls upon the ſame ſea, and by the current which is conſtantly running from the Atlantic ocean into the Mediterranean through the ſtreights of Gibraltar.

It may naturally be enquired by what means water, which is ſo much heavier than air, is converted into a fluid ſo light as to float in air; and how does it remain ſuſpended and diſperſed therein, ſometimes without the leaſt tendency to ſeparation.

Various hypotheſes have been offered in explanation of this ſubject; but I ſhall not detain my reader by the account of opinions that are always inſufficient, and frequently abſurd. The moſt remarkable facts, which may aſſiſt the inquiſitive mind in the inveſtigation of the ſubject, are as follows:

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* The vapour of ſea water does not take up any ſaline particles.

† Phil. Tranſ. N. 212.

If

If the ſteam of water be examined by means of lenſes or microſcopes, no regular bodies or configuration of particles will be diſtinguiſhed in it.

There is an evident attraction between water and air, viz. the attraction of coheſion *. If a ſmall bubble of air be introduced in a glaſs veſſel filled with boiled water, and inverted in water, that quantity of air will diſappear in a day or two.

Heat, which diminiſhes the attraction of aggregation between the particles of water, muſt of courſe render the attraction between air and water more active; but, *cæteris paribus*, hot air is a better ſolvent of water, than colder air. The cooling of hot atmoſpherical air is generally accompanied with a depoſition of water, which, according to the quantity of water previouſly contained in the air, and the greater or leſs alteration of temperature, aſſumes the form of miſts, or clouds, or rain: and on the other hand, the heating of air is attended with a diſſipation of vapour, and an increaſe of tranſparency; hence, as the ſun riſes, the miſtineſs of the night air, when no other circumſtance inter-

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* It is impoſſible to annex more appropriate names to indefinite, or unſettled, ideas. Certain it is, that water will abſorb a quantity of air, and that air abſorbs a certain quantity of water; and to thoſe abſorbing powers we give the name of *attraction* or *diſſolving property*; whether they are really owing to the attraction of coheſion, properly ſo called, or not.

venes,

venes, is gradually diſſipated, and the atmoſphere clears up; hence, in this country, the ſoutherly and weſterly winds, which drive the air from warmer climates, generally bring rains or miſts; whereas the contrary effect is moſtly produced by northerly or eaſterly winds, which bring the air from colder regions. But the ſame change of temperature is not always accompanied with the ſame diſſipation or depoſition of water in the atmoſphere.

It has been fully eſtabliſhed, by the reſult of a variety of experiments, that when water is converted into ſteam or vapour, it abſorbs a quantity of heat, which is neceſſary to its elaſtic ſtate; (for the ſteam of water is elaſtic, viz. it may be compreſſed, or expanded, by the addition or diminution of preſſure.) This quantity of heat is depoſited when ſteam aſſumes the form of water.

If you moiſten part of your hand, and then blow upon it for the purpoſe of increaſing the evaporation, you will feel that part of the hand ſenſibly cooled, viz. the water, in its aſſuming the form of ſteam, robs the hand of part of its heat. If you place your hand over the ſteam of boiling water, the hand is much warmed by the heat which the ſteam depoſits upon it in its reaſſuming the form of water.

It is a common practice amongſt ſailors, to moiſten one of their fingers by putting it into the mouth, and then to expoſe it above their head; by which means they can tell which way the wind blows;

blows; for that ſide of the finger which is expoſed to the wind, feels colder than the reſt, the evaporation on that ſide being promoted by the wind.

Beſides the abſorption of heat, the evaporation of water (as has been fully aſcertained by the very able Profeſſor Volta), is alſo attended with an abſorption of electric fluid; and on the other hand, the converſion of ſteam into water is attended with a depoſition of electric fluid. The experiments, which prove thoſe facts, will be found in the third part of theſe Elements, in the Section for Electricity.

It ſeems, therefore, that the formation of vapour, or clouds, or fogs, or rain, and ſuch like phenomena, depends upon the concurrence of all the above-mentioned circumſtances, and perhaps the formation and duration of each phenomenon in particular depends upon the various degrees of thoſe different circumſtances, which neceſſary degrees are by no means known.

The moiſture of the atmoſphere, or rather that quantity of water which is not in perfect ſolution with the air, but has not yet acquired the form of water, is meaſured by an inſtrument, called the *hygrometer*. The rain, or that quantity of water which falls from the clouds, or is depoſited by the air in viſible drops, is meaſured by means of another inſtrument, called the *pluviometer* or *rain-gage.*

gage. Theſe inſtruments will be deſcribed at the end of this chapter.

The rain, which, as has been ſaid above, conſiſts of the water that has been exhaled from the ſurface of the terraqueous globe, either falls in very ſmall particles of little gravity, in which caſe it is more properly called *dew*[*], or *miſt* or *fog*; or elſe it falls in larger drops of various ſizes, in which caſe it is properly called *rain.*

When the clouds are near, as is moſtly the caſe in the winter ſeaſon, or upon mountains, the drops of rain are ſmall, not having time ſufficient to join and to grow large. But when the clouds are very high, as is the caſe in the ſummer ſeaſon, or in hot climates, the drops are much larger, and the rain very copious. A rain-gage, placed upon the ſurface of the earth, receives a greater quantity of rain in the ſame time, than a ſimilar gage, which is ſituated higher up. A few feet difference of perpendicular altitude make a conſiderable difference[†]. The quantity of rain is expreſſed by inches and tenths; thus, if it be ſaid that 20,3 inches of rain fell in one year in London, the meaning is, that if the ſurface of London had

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[*] The *dew*, properly ſpeaking, is that moiſture which falls during the abſence of the ſun, and without the neceſſary preſence of clouds.

[†] See the Phil. Tranſ. vol. 59th. art. 47. and vol. 67th. p. 255.

been perfectly flat, and all the rain that fell upon it throughout that year, had remained upon it without evaporation, draining, or abſorption, the depth of it would have amounted to 20,3 inches. Therefore, if a veſſel open at top, and having ſtraight up ſides, be expoſed to the atmoſphere ſo as to receive the rain, and is ſo conſtructed as to prevent evaporation; the depth of water accumulated in that veſſel, will ſhew the quantity of rain for the adjacent country, and the veſſel itſelf is a rain-gage.

The quantity of rain which falls daily or annually in various parts of the world, has been, and is, frequently meaſured and regiſtered; but it might be wiſhed that ſuch obſervations were inſtituted in a great many more places; for, conſidering how unequal and partial rains are, we muſt conclude, that the indication of a rain-gage will ſerve for no great extent of circumjacent country.

The rains on the vicinity of hills or mountains, or foreſts, are generally more copious than in other places. In ſeveral places, eſpecially within the torrid zone, the rain is ſeldom ſeen. It has been aſſerted, as a real though ſingular fact, that it never rains in the kingdom of Peru; but that during part of the year the atmoſphere over the whole country is obſcured by thick fogs, called *garuas* *.

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* D'Ulloa's Voyage to South America, vol. II. p. 69.

A rain-gage is kept expoſed over the apartments of the Royal Society in London, and its contents are noted frequently. It appears from that regiſter, that a mean of the annual quantity of rain in London amounts to little more than 21 inches, but a conſiderable inequality exiſts between the quantities for the ſingle years; for ſometimes, as in the year 1791, the quantity of rain is about 15 inches, and at other times, as in the year 1774, as alſo in 1779, the rain amounts to 26 inches and upwards.

At Upminſter, in Eſſex, the annual average of rain is 19,14.

At Liverpool it is 37,43 inches.

At Townley, in the neighbourhood of the hills which divide Lancaſhire and Yorkſhire, it is 41,516 inches.

At Lyndon, in Rutland, it is 24,6 inches.

At Dublin, in Ireland, it is about 22,25 inches.

At Paris, the annual average is 20,19 inches.

At Liſle, in France, it is 24 inches.

At Zuric, in Swiſſerland, it is 32,25 inches.

At Piſa, in Italy; it is 43,25 inches.

"The annual quantity of rain," *as Dr. Dobſon juſtly obſerves*, "is a very uncertain teſt of the "moiſture or dryneſs of any particular ſeaſon, "ſituation, or climate. There may be little or "even no rain, and yet the air be conſtantly damp "and foggy; or there may be heavy rains, with

" a comparatively dry ſtate of the atmoſphere.
" The ſame depth of rain will likewiſe produce
" different effects on the air, according as it falls
" upon a flat or hilly country; for large quantities
" ſoon quit the hills, or high grounds, while
" ſmaller quantities have more laſting and powerful
" effects on a flat country. Much alſo depends
" upon the nature of the ſoil, whether clay
" or ſand, whether firm or compact, or looſe and
" ſpongy."

" Is not evaporation, therefore, a more accurate
" teſt of the moiſture or dryneſs of the atmoſphere,
" than the quantity of rain * ?"

But if it be conſidered that the evaporation from the ſurface of water only, is far different from the evaporation from the diverſified ſurface of a country; the uncertainty of the latter method will appear equally great.

The hygrometer ſhews, that in general the moiſture of the atmoſphere is greater in low ſituations, than in more elevated places: but the moſt remarkable, and at the ſame time the moſt unaccountable, part of the ſubject is, that ſometimes, (as has been obſerved by ſcientific perſons) on mountains and other elevated ſituations, whilſt the thermometer is ſtationary, and the hygrometer ſhews a conſiderable degree of actual and even increaſing dryneſs, clouds are quickly formed, and often a copious rain ſucceeds; whereas, at

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[*] Phil. Tranſ. vol. 67th. p. 244.

at other times, a thick or clouded atmoſphere quickly clears up, and that without any apparent cauſe.

It ſeems as if the vapour of water changed its nature by being diſperſed through the atmoſphere. But we are certainly ignorant of that particular diſpoſition in the atmoſphere, which produces ſo great a change. We find, for inſtance, that clouds of immenſe extent, ſometimes riſe from the horizon; that inſtead of being driven by the exiſting wind, they actually change its direction; that other clouds are quickly formed. A great ſtorm enſues; the rain is abundant; every thing acquires a conſiderable degree of moiſture; yet an hour after, the ſerenity of the air is reſtored, and the natural proceſs of evaporation becomes as vigorous as ever.

The quantity of evaporation from the land is, in general, much leſs than the rain which falls upon the ſame; whereas, from the ſurface of the ſea, lakes and rivers, the evaporation exceeds the rain. The like difference does alſo exiſt between cold and warm climates. But the action of the winds, and the running of the ſuperfluous rain-water from the land again into the ſea, compenſates the deficiencies, and keeps up a uſeful, neceſſary, and admirable circulation.

We ſhall now endeavour to explain the principle and conſtruction of hygrometers, as alſo of the rain-gage.

It has already been ſhewn, that in virtue of the attraction of coheſion or capillary attraction, various ſubſtances are capable of abſorbing moiſture into their pores, or at leaſt of holding it attached to their ſurface. If then the air contain a quantity of moiſture, and a certain other dry ſubſtance has a greater attraction towards water than air has, then the moiſture will quit the air, and will attach itſelf to that other ſubſtance; in conſequence of which that other ſubſtance will be enlarged in its dimenſions, or will be increaſed in weight. Now by meaſuring the diminiſhed or increaſed dimenſions, or the increaſed or diminiſhed weight of that other ſubſtance, at different times, we acquire a knowledge of the quantity of water which has been depoſited or abſorbed by the air at thoſe times. The inſtrument in which a ſubſtance fit for this purpoſe (called an *hygroſcopic body*) is ſo ſituated as to ſhew a very ſmall alteration of its length, or weight, is called an *hygroſcope* or *hygrometer*.

A vaſt number of animal, vegetable, and mineral ſubſtances are ſuſceptible of thoſe alterations, but moſt of them are far from being fit for ſuch an inſtrument. The twiſted fibres of wild oats, a ſea-weed, ſalted ſtrings, pieces of deal cut acroſs the grain, a piece of cat-gut ſtring, &c. are commonly uſed as indicators of moiſture or dryneſs; but ſuch ſubſtances are not fit for philoſophical purpoſes; for they are unequal in their actions; their power of abſorbing water increaſes or decreaſes, and ſometimes entirely ceaſes in proceſs of time;

and very ſeldom two inſtruments, that are furniſhed with ſuch ſubſtances, can be compared together.

Mr. De Luc, and Mr. De Sauſſure, both gentlemen of great knowledge and ingenuity, have examined a vaſt number of hygroſcopic ſubſtances in a great variety of circumſtances; and, upon the whole, the latter of thoſe gentlemen found reaſon to prefer a hair*; whilſt the former prefers a very fine ſlip of whale-bone cut acroſs the grain. Either of thoſe ſubſtances is to be placed in a proper frame, which ſhews their elongations or contractions to a very minute quantity; the inſtrument, or at leaſt that part of it which holds the hygroſcopic ſubſtance, is placed in water, which extends the ſubſtance to the utmoſt, and the point where the extremity of the ſubſtance reaches, is marked upon the inſtrument, and is called the *point of extreme moiſture.* Then the inſtrument is removed from the water, and is placed into a large veſſel almoſt full of unſlacked quick-lime, wherein it is kept for a few days; for as quick-lime has a conſiderable property of abſorbing water copiouſly but ſlowly, the air in that veſſel is very dry, and its degree of dryneſs is conſtantly the ſame during ſeveral months, notwithſtanding the opening of the veſſel, which muſt take place for putting in or taking out the hygrometers. By this means the *point of greateſt*

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* See his Work on Hygrometers, 2 vols. quarto.

dryneſs is obtained. Then the diſtance between this point and the point of greateſt moiſture, is divided into one hundred parts, and thoſe parts are called the degrees of the hygrometer, or the degrees of moiſture *.

Thoſe two ſorts of hygrometers are tolerably uniform, and pretty quick in their action. Two or more of them are alſo comparable within a ſmall difference. As upon the whole it appears that Mr. De Luc's hygrometer has ſome advantages over that of Mr. De Sauſſure's, I ſhall therefore deſcribe it in Mr. De Luc's own words. See fig. 1. of Plate XV.

Thoſe inſtruments may be made of various ſizes, but they are moſtly made of about twice the ſize of the figure.

" Their frame will ſufficiently be known from " the figure; therefore I ſhall confine myſelf to " the deſcription of ſome particulars. The *ſlip of* " *whale-bone* is repreſented by *a b*, and at its end " *a* is ſeen a ſort of *pincers*, made only of a flattened " bent wire, tapering in the part that holds the " *ſlip*, and preſſed by a ſliding ring. The end *b* " is fixed to a moveable bar *c*, which is moved by " a ſcrew for adjuſting at firſt the *index*. The end *a* " of the ſlip is hooked to a thin braſs wire; to

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* From the point of greateſt dryneſs to that of greateſt moiſture, a ſlip of whale-bone will be increaſed about one-eighth of its length.

" the other end of which is alſo hooked a very thin " ſilver gilt *lamina*, that has at that end *pincers* ſimilar to thoſe of the *ſlip*, and which is fixed oy the " other end to the axis, by a pin in a proper " hole. The *ſpring*, *d*, by which the *ſlip* is ſtretched, is made of ſilver-gilt wire; it acts on the *ſlip* " as a weight of about 12 grains, and with this advantage over a *weight* (beſides avoiding ſome " other inconveniencies) that, in proportion as the " *ſlip* is weakened in its lengthening, by the penetration of moiſture, the *ſpring*, by unbending at " the ſame time, loſes a part of its power. The " *axis* has very ſmall pivots, the *ſhoulders* of which " are prevented from coming againſt the frame, by " the ends being confined, though freely, between " the flat bearings of the heads of two *ſcrews*, the " front one of which is ſeen near *f*. The ſection " of that *axis*, of the ſize that belongs to a *ſlip* of " about 8 inches, is repreſented in fig. 2.; the " *ſlip* acts on the diameter *a a*, and the *ſpring* on the " ſmaller diameter *b b* *.

After an aſſiduous and judicious uſe of hygrometers, made in the courſe of 20 years and upwards, Mr. De Luc formed ſome very uſeful deductions, which I ſhall ſubjoin in his own words.

" From thoſe determinations in *hygrometry*, " ſome great points are already attained in *hygrology*,

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* De Luc's Paper in the Phil. Tranſ. vol. 81ſt. part II.

“ meteorology, and chemiſtry, of which I ſhall
“ only indicate the moſt important. 1ſt. In the
“ phænomenon of *dew*, the graſs often begins to
“ be *wet*, when the *air* a little above it is ſtill in a
“ middle ſtate of *moiſture*; and *extreme moiſture* is
“ only certain in that *air*, when every ſolid expoſed
“ to it is *wet*. 2dly. The *maximum* of *evaporation*,
“ in a cloſe ſpace, is far from identical with the
“ *maximum* of *moiſture*; this depending conſiderably,
“ though with the conſtant exiſtence of the other,
“ on the *temperature* common to the *ſpace* and to
“ the water that evaporates. 3dly. The caſe of
“ *extreme moiſture* exiſting in the open tranſparent
“ air, in the day, even in the time of *rain*, is extremely
“ rare: I have obſerved it only once, the
“ temperature being 39°. 4thly. The *air* is *dryer* and
“ *dryer*, as we aſcend in the atmoſphere; ſo that in
“ the upper attainable regions, it is conſtantly very
“ *dry*, except in the *clouds*. This is a fact certified
“ by Mr. De Sauſſure's obſervations and mine.
“ 5thly. If the whole atmoſphere paſſed from *extreme*
“ *dryneſs* to *extreme moiſture*, the quantity of
“ *water* thus *evaporated* would not raiſe the *barometer*
“ as much as half an inch. 6thly. Laſtly,
“ in chemical operations on *airs*, the greateſt
“ quantity of *evaporated water* that may be ſuppoſed
“ in them, at the common *temperature* of
“ the atmoſphere, even if they were at *extreme*
“ *moiſture*, is not ſo much as $\frac{1}{100}$ part of their
“ maſs. Theſe two laſt very important propo-

" ſitions have been demonſtrated by Mr. De " Sauſſure*."

The mean height, for the whole year, of De Luc's hygrometer, expoſed to the atmoſphere in London, is about 79 degrees. It muſt, however, be obſerved, that hygrometers of every ſort, even the above deſcribed one of Mr. De Luc, are very liable to be ſpoiled by long expoſure; as duſt, ſmoke, inſects, &c. are apt to adhere to them; in which caſe their rate of going, or ſenſibility, is altered conſiderably. The proper action of De Luc's hygrometer may, in ſome meaſure, be preſerved, by now and then placing the inſtrument in water, and gently cleaning the ſurface of the whalebone ſlip, by means of an hair-pencil.—A ſteadier and more durable hygrometer is ſtill a deſideratum in natural philoſophy.

Evaporation generates cold, and the quicker the evaporation takes place, the greater is the cold which is produced: therefore, if the bulb of a thermometer be juſt moiſtened, and then be expoſed to the air, the mercury will deſcend lower when the evaporation is performed quicker, and *vice verſa.* Upon this principle Mr. Leſlie has conſtructed an inſtrument, which ſhews the quick-

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* De Luc's Paper in the Phil. Tranſ. vol. 81ſt. part I. See alſo his Paper on *Evaporation* in the Phil. Tranſ. for the year 1792, part II. for farther illuſtration of the ſubject of Hygrometry.

neſs of evaporation. The inventor calls it an hygrometer; but the quickneſs of evaporation does not indicate the moiſture of the air in all caſes *.

The principle of the rain-gage has already been ſhewn in page 414. The rain-gage which is moſtly uſed, is delineated in fig. 3. of Plate XV. It is an hollow veſſel, of tined iron plates, japanned inſide and out. The whole machine conſiſts of three parts. A B C D is a cylindrical veſſel, to the aperture of which the funnel F E *x* is nicely fitted. The upper part of the funnel has an edge of braſs, which is perpendicular to the horizon, as is ſufficiently indicated by the figure.

This gage, when expoſed to the atmoſphere, receives the rain which goes through the aperture *x* of the funnel, into the receiver A B C D; out of which it cannot evaporate, either out of the joint A D, which is very cloſe, or out of the hole *x*, which, beſides it being ſmall, is partly occupied by the meaſuring rod. The meaſuring rod G H is faſtened to an hollow float H, of japanned tin plates, which floats upon the water; and as the water fills the cylindrical veſſel A D B C, ſo the float is raiſed, and part of the meaſuring rod comes out; and the diviſions of the rod, which are out of the funnel,

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* See the deſcription of this Hygrometer in Nicholſon's Journal, vol. II. p. 461.

ſhew

ſhew the quantity of water which is in the cylindrical veſſel.

With reſpect to the diviſions of the rod, it muſt be obſerved, that when the edge of the funnel and the cylindrical veſſel are of the ſame diameter, then the diviſions of the rod muſt be only inches and tenths, in order to ſhew the quantity of rain in inches and tenths; but when the diameter of the cylindrical veſſel is leſs than that of the edge F E, then the diviſions muſt be longer, becauſe an inch depth of rain, in an area of a certain diameter, will be more than an inch depth in an area ſmaller than that.—Thoſe gages are made of various ſizes, and the diviſions of the meaſuring rod are made ſo as to indicate the inches of rain that would be accumulated in a cylindrical veſſel whoſe diameter equalled the diameter of the braſs edge F E.

A croſs-bar with a ſocket, through which the meaſuring-rod paſſes, may be ſeen within the funnel. This ſerves to render the diviſions of the meaſuring rod more legible. When no water is contained in the gage, and of courſe the float reſts upon the bottom B C, then the o, or the beginning of the diviſions of the rod is even with the upper part of the above-mentioned croſs-bar.

CHAPTER XIV.

THE DESCRIPTION OF THE PRINCIPAL MACHINES, WHICH DEPEND UPON THE FOREGOING SUBJECTS OF FLUIDS.

IN laying down the theory of fluids, both elaſtic and non-elaſtic, I have deſcribed as few machines, and thoſe of as ſimple a conſtruction, as the nature of the ſubject could admit of. This I have done, in the firſt place, for the purpoſe that the reader might not conſider the knowledge of ſuch ſubjects as unattainable, without the uſe of coſtly machines; and, ſecondly, that the connection of the theoretical reaſoning might not be interrupted by the introduction of long and complicated deſcriptions.

But it is now, however, neceſſary to explain the conſtruction and the uſe of thoſe machines which have been contrived for the purpoſe either of meaſuring, or of elucidating, or, laſtly, of applying to our purpoſes, the mechanical properties of fluids. And here we ſhall beſtow our attention more on the principles than upon the variety of ſuch machines.

The Syphon, or Crane.

A tube of glaſs, or metal, or other ſolid ſubſtance, open at both ends, and bent like the repreſentation of fig. 4. Plate XV. is called a *ſyphon* or *crane*, and is commonly uſed for decanting liquors from one veſſel into another. It is an indiſpenſable requiſite in the conſtruction of this inſtrument, that the perpendicular altitude of the diſcharging leg A B, be greater than that of the ſucking leg A C, (reckoning from A to the ſurface of the liquor, in which the leg A C is immerſed). Then, when the aperture C is in the liquor, if, by applying the mouth at B, and ſucking the air out of the ſyphon, its cavity be filled with the liquor; on removing the mouth, the liquor will run out of the aperture B, and will continue to run as long as you continue to ſupply the veſſel F with fluid, or as long as the ſurface of the fluid in the veſſel F remains higher than the level of the aperture B.

The cauſe of this effect is the preſſure of the atmoſphere; for when the ſyphon is full of liquor, the preſſure of the atmoſphere at B and C keeps the liquor up in the legs of the ſyphon; and that preſſure is partly counteracted by the perpendicular altitudes of the liquor in thoſe legs; but that counteraction is leſs at C than at B, becauſe the perpendicular altitude A C is leſs than A B; therefore the

the atmoſphere preſſing at C, or (which is the ſame thing) on the ſurface of the liquor in the veſſel F, more than at B, forces the liquor to run through the ſyphon.

It is evident that it is immaterial whether the diameters of the two legs be equal or not, provided the diſparity be not ſo great as to introduce the obſtruction from capillary attraction, &c.—Whether the legs be bent in various directions or not, is alſo immaterial; provided the perpendicular altitude of the diſcharging leg be greater than that of the other.

It is alſo evident, from the theory, that the crane cannot act if the perpendicular altitude of its legs exceed 32 feet or thereabout. Nor can a ſyphon act in vacuo.

The beſt ſyphons that are at preſent in uſe for decanting liquors, have certain appendages which render their uſe more commodious. Fig. 5. of Plate XV. repreſents one of the beſt conſtruction. It has a ſtop-cock D at the diſcharging aperture, and a ſmall tube which runs along the outſide of that leg, and communicates with the cavity of that leg juſt above the ſtop-cock. When the aperture C is ſituated within the liquor, the ſtop-cock is cloſed, and the mouth which ſucks the air out, &c. is applied at E. Some of thoſe ſyphons have no ſtop-cock, in which caſe the aperture B muſt be cloſed by the application of a finger, whilſt the air is ſucking out at E.

If

If ſeveral threads of cotton, a bunch of graſs, or ſome ſimilar ſubſtance, be placed partly in a glaſs of water, and the other part (being the longeſt of the two) be left hanging out of the glaſs, as is ſhewn in fig. 15. of Plate XI.; the cotton or other ſubſtance will gradually abſorb the water, in virtue of the capillary attraction; and when the whole is moiſtened ſufficiently, the cotton, or other ſubſtance, will act as a ſyphon, and the water will keep dropping out of the external part of it.

A little machine, called *Tantalus's cup*, acts upon this principle, and its conſtruction is as follows:

There is a hole quite through the bottom of a cup A. Fig. 6. Plate XV. and the longer leg of a ſyphon D E B G is cemented into the hole, ſo that the end D of the ſhorter leg D E may almoſt touch the bottom of the cavity of the cup. Now if water, or other liquor, be poured into the cup, the water will riſe into the leg D E of the ſyphon, as it does in the cup, and will drive the air from that leg through the longer leg E G; but when the water has reached the upper part F of the ſyphon, it will not only run down and fill the other leg F G, but it will keep running out at G, until the cup is quite emptied. A little figure is ſometimes placed over the ſyphon D F B, with the mouth open a little above F, which figure conceals the ſyphon, and repreſents Tantalus, who is deprived of the water, when the water has riſen ſo high

high within the cup, as nearly to reach his mouth.

The reaſon, which principally induced me to deſcribe the above-mentioned cup, is, that its action explains a curious natural phenomenon, viz. that of *intermitting* or *reciprocating ſprings*, called alſo *ebbing and flowing wells*.

There are certain ſprings or ſtreams of water which iſſue out of rocks, and are rather copious for a certain time, then ſtop, and, after a certain period, come out again. The intermitting period is various, but ſometimes it is very regular. The origin of thoſe ſprings is, with great probability, owing to the following conformation, or to ſomething ſimilar to it.

A A, fig. 19. Plate XV. repreſents the perpendicular ſection of a hill, within which is a cavity B B, and from this cavity a natural channel runs in the direction B C D E, forming a natural ſyphon. The rain water, which deſcends from the upper part of the hill through various ſmall crevices, G, G, G, gradually fills the cavity B B, as alſo the part B C of the channel, or ſhorter leg of the ſyphon; but when the water gets above the level of C, then a ſtream will run through the channel, and out of it at E, until the cavity B B, as alſo the channel B C D E is quite emptied; it being ſuppoſed that the draining of the water through the crevices G, G, G, cannot ſupply the cavity B B, ſo faſt as it is drained by the channel B C D E. Then

Then the flow of water at E ſtops, until ſo much water is again accumulated in the cavity BB, as to reach the level of C, at which time the ſtream reappears at E; and ſo on.

The Water Pump.

There are ſeveral ſorts of pumps for drawing water out of wells, ſprings, &c.; but they may be reduced to two ſorts, viz. the common pump, generally called the *ſucking pump*, and the *forcing pump*.

Fig. 15. Plate XV. repreſents a pump of the firſt ſort. AB is a cylindrical pipe open at both ends, the lower of which is immerſed in the water of the well, &c. Towards the lower part, as at C, there is a ſtopper with a hole and a valve, which opens upwards when any fluid puſhes it from below, but is cloſed by any ſuperincumbent force*. In the upper part of the tube there is a piſton

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* A valve is a piece of mechaniſm, that belongs almoſt to all ſorts of hydraulic and pneumatic engines. Valves are made of different ſorts, of which however the following are the principal.

Fig. 12. Plate XV. repreſents a ſtopple, with an oil ſilk valve; viz. a narrow ſlip of oil ſilk is ſtretched over the upper flat part of the ſtopple, ſo as to cover the central hole; and, being turned over the edge, is tied faſt round

piſton D, faſtened to the handle or rod E, which generally is an iron rod. The piſton conſiſts of a piece of wood, nearly equal to the diameter of the cavity of the pump; but being covered over its cylindrical part with leather, it fits pretty tightly the cavity of the pump. In this piſton there is a hole and another valve, like the one at C, which alſo opens upwards. The action of pumping conſiſts in alternately moving the piſton a certain way up and down, by which means the water aſcends through the pump, and comes out of its upper aperture, or out of the ſpout F, when the upper part of the pump is furniſhed with ſuch veſſel and ſpout as is ſhewn in the figure. The action of this pump depends upon the gravity or preſſure of the atmoſphere; hence it could not poſſibly act in vacuo.

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round the ſtopple, as is indicated by the figure. In fig. 13, a flat and thick piece of leather is adapted to the upper flat part of a ſtopple, ſo as to cover the central hole. It has a little prolongation on one ſide, which is faſtened to the ſtopple by means of a nail or ſcrew, and a piece of lead is faſtened to the upper part of the leather, in order to let it lay flat upon the hole. In fig. 14, the central hole is made a little conical at its upper part, and is ſhut up by a conical piece of metal, which reſts upon it by its own gravity.

It is evident that a force from below will open any one of thoſe valves; but a force from above will ſhut up the aperture more effectually.

When the piſton is firſt drawn upwards, the air in C D is rarefied; hence the preſſure of the atmoſphere upon the ſurface of the water in the well forces the water to aſcend a little way into the lower part of the pump; for inſtance, as high as G. Then the piſton is puſhed downwards, which contracting the diſtance C D, forces ſome air out of the valve D through the piſton, but no air can get down through the valve at C; hence the water remains at G. After this, the piſton is drawn upwards a ſecond time, which rarefies the air in C D; in conſequence of which the water aſcends higher within the pump; thus, by degrees, the water gets above the valve C, and fills the ſpace C D; and when this takes place, then, by lowering the piſton, ſome water paſſes through the valve D, and remains above the piſton; then, on lifting up the piſton, that water is raiſed, and more water comes from the well through the valve C, &c.

It is hardly neceſſary to mention, that the height of the valve D, above the water of the well muſt never exceed 32 feet. Indeed, on account of the imperfections to which thoſe mechaniſms are ſubject, that height can ſeldom exceed 20 feet.

The force which is required to work a pump is as the height to which the water is raiſed, and as the ſquare of the diameter of the pump at the place where the piſton works; it being immaterial whether the reſt of the pump be of the ſame diameter or not.

Pumps, in general, are worked not by applying the power immediately to the rod at E; but the end of that rod is connected with the ſhorter arm of a lever, whilſt the power is applied to the longer arm of the lever; and ſince the longer arm of the lever is about five or ſix times as long as the other, therefore the power is by this means increaſed five or ſix times.—It has been found from repeated trials, that when the handle increaſes the power five times, when the diameter of the pump is four inches, and the water is to be raiſed 30 feet high; the ordinary exertion of a labouring man can work it for a moderate continuance of time, and can diſcharge 27½ gallons of water (Engliſh wine meaſure) per minute.

Now, from the above-ſtated particulars, it will not be difficult to calculate the dimenſions of a pump, which will diſcharge a given quantity of water at a certain height in a determinate time; and what power will be required for the purpoſe.

The *forcing-pump*, fig. 16. Plate XV. raiſes the water above the valve H, in the ſame manner as the preceding pump; but then, on lowering the piſton, which in this pump is a ſolid piece without any valve or perforation, the water cannot get above it, but it is forced through the tube M N, and through the valve at P, into the veſſel K K, which is called the *air-veſſel* or *condenſing-veſſel*. Thus, by repeated ſtrokes of the piſton, the water is forced to enter, and to accumulate into the veſſel K K. driving the air out of it, through the pipe I G F, But when the water has been raiſed above the aperture I of the pipe, then the air, inſtead of being driven out, is condenſed in the upper part of the air-veſſel; hence it begins to re-act upon the water by its elaſticity; in conſequence of which the water is forced out of the pipe I H F, forming a jet, which riſes higher, or goes farther and farther, according as the water is forced into the air-veſſel with greater quickneſs, and the air in the upper part of the ſaid veſſel is contracted into a narrower ſpace, by the riſing of the water at O, within the veſſel.—Some forcing-pumps have no air-veſſel, but convey the water through a ſingle uniform tube to the required height.

The jet, when there is an air-veſſel, comes out without intermiſſion; for whilſt the piſton is aſcending, the elaſticity of the condenſed air continues to act upon the water at O.

By means of this pump, the water may be raiſed to any height, provided there be working power adequate to the required effect, and the parts of the pump, and principally of the air-veſſel, be ſufficiently ſtrong.

If to the extremity F of the diſcharging pipe, a flexible tube, either of leather, or of other pliable material, be adapted, ſo as to render the jet capable of being directed towards any particular place at pleaſure, then the mechaniſm becomes a *fire-engine.*

The principle of *fire-engines,* which are commonly uſed in this country, and elſewhere, for extinguiſhing fires, is nothing more than what has been already deſcribed. Their particular conſtructions, which have been diverſified and improved by various able mechanics, differ only in a more or leſs compact diſpoſition of parts; in having two or more forcing pumps; in having the levers capable of admitting ſeveral working-men, &c.

Water-pumps of every ſort may be worked by other powers, beſides the force of men. They may be worked by the wind, by horſes, by a ſteam-engine, by a river, &c. A vaſt variety of mechaniſms has been contrived for ſuch purpoſes, which may be ſeen in almoſt all the works on mechanics, hydraulics, and other ſubjects allied to them; but thoſe mechaniſms muſt be contrived according to the particular circumſtances of the ſituations, in which they are to be uſed.

The water-works at London-bridge conſiſt of forcing-pumps, which are worked by the current of the river, viz. the current of the river turns a large vertical wheel, called the water-wheel, the axis of which has a number of cranks, which work as many levers, and at the ends of thoſe levers are faſtened the rods of the forcing-pumps. The water is forced by them into a very ſtrong condenſing veſſel of iron, and from this veſſel various pipes convey and diſcharge the water to different parts of the town.

Archimedes' Screw-Engine for raiſing Water.

This ſimple and elegant contrivance of the great Archimedes, is ſhewn in fig. 18. Plate XV. It conſiſts of a ſcrew-like tube, open throughout, and faſtened round an axis, which turns, together with the tube, round the pivots A, B.

This machine being placed with its lower part in water, muſt be inclined to the horizon at an angle of about 45 degrees; then by turning the handle M, the machine muſt be turned in the direction *d a* C; viz. ſo that the loweſt aperture of the tube may go againſt the water; and by this means the water will be raiſed from A, and will be diſcharged by the upper aperture *i*, into a proper veſſel, S, which muſt be placed under it, to receive the water, and to convey it wherever it may be required.

In order to underſtand the action of this machine it muſt be conſidered, 1ſt, That every ſucceſſive part or point in the length of the tube, is farther and farther from the loweſt part of the machine, or is nearer and nearer to the aperture *i*. 2dly, That the ſmall quantity of water which is in the inferior part *d*, of any convolution of the tube, cannot (in virtue of its gravity) remain affixed to that identical part of the tube, when, by the turning of the machine, that part comes to the higher ſituation *a*; but it muſt paſs on to the next part of the tube, then to the next to that, and ſo on. But thoſe ſucceſſive parts come nearer and nearer to the aperture *i*; therefore that quantity of water muſt paſs gradually from the loweſt to the higheſt part of the tube, until it comes out itſelf of the aperture *i*.

What has been ſaid of this quantity of water, may evidently be ſaid of the next, and, in ſhort, of all the water which is raiſed by the machine.

Inſtead of the handle M, ſometimes a pretty large wheel is affixed to the loweſt part of the machine, which, on account of the inclination, will be partly immerſed in water; in conſequence of which, the machine will be turned by the water itſelf; ſuppoſing that water to be a river, or running ſtream.

Sometimes, inſtead of one, two tubes are fixed round the axis of this machine; but its conſtruction has been altered various ways, which need not be particularly deſcribed, ſince the principle itſelf of the machine remains unaltered.

Such machines are uſeful for raiſing water to no great heights; for when the elevation is conſiderable, the machine, on account of its inclined poſition muſt be long, heavy, and liable to be bent, in which caſe its action would ceaſe.

The Rope Machine for raiſing Water.

If a vertical grooved wheel, fixed in a frame, be ſituated within the wáter at the bottom of a well, and another ſimilar wheel, having a handle affixed to its axis, be ſituated in another frame at the upper part of the well; alſo an endleſs rope (viz. a rope whoſe two extremities are ſpliced into each other) be paſſed round both wheels; then, on turning the handle, the wheels and the rope will be cauſed to move, viz. the rope will aſcend on one ſide, and will deſcend on the other, paſſing ſucceſſively through the water of the well; but the aſcending part will carry up a quantity of water adhering to its ſurface; and this water differs in quantity, according to the ſize of the rope, the depth of the well, and the quickneſs of the motion; viz. with a larger rope, in a leſs deep well and quickeſt motion, a greater quantity of water will be raiſed, than otherwiſe.

In order to intercept the water at the top of the well, the upper wheel is incloſed in a pretty large box, in the bottom of which there are two holes, through which the aſcending and deſcending parts of the rope paſs. To theſe holes are affixed two ſhort tubes, which prevent the exit of the water which falls to the bottom of the box. There is alſo a lateral ſpout on the ſide of the box, cloſe to the bottom, for the water to come out of; and on the

the broad ſides of the box there are two holes for the axis of the wheel. The 11th and 10th figures of Plate XV. exhibit a ſection and a front view of a machine of this ſort, which was put up in the year 1782, on the caſtle hill at Windſor, where the depth of the well is 95 feet *.

The ſame letters refer to the like parts in both figures.

The wheel H at the bottom of the well is of *lignum vitæ*, one foot in diameter. Its axis is of ſteel, and turns with its extremities in ſockets of bell-metal.

The frame II is of iron.

The wheel EE at the top of the well is of iron; but its rim, with the grove which receives the rope, is of lead. The diameter of this wheel is three feet.

The axis *dd* is of ſteel, and its extremities turn in bell-metal ſockets, which are fixed in two upright poſts AA, that ſupport the machine. T is the handle affixed to the axis, which handle deſcribes a circle of 28 inches in diameter; *b b* is the wooden box, lined with lead, which incloſes the wheel E. FF are the holes at the bottom of the box through which the rope paſſes. Their diameter is about two inches.

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* A ſimilar machine was alſo placed on the round tower of Windſor caſtle, which draws the water from the depth of 178 feet.

On the ſame axis *dd,* another wheel CC, of about four feet in diameter, is fixed. This wheel is of wood, loaded on the edge with lead, and it ſerves as a fly to facilitate the motion.

The rope is of horſe-hair, and meaſures half an inch in diameter.

With this identical machine, ſeveral experiments were tried, the reſult of which is as follows:

When the machine was worked ſlowly, viz. ſo as to make about 30 revolutions of the handle in one minute, then very little water came up adhering to the rope; and of this water a very ſmall portion was ſeparated from the rope within the box, ſo as to come out of the ſpout Z, in the ſide of the box.

When the revolutions of the handle were about 50 in a minute; then a conſiderable quantity of water came up adhering to the rope; and on turning the wheel EE round, the greateſt part of that water, having acquired a conſiderable velocity, flew off in a tangent from the rope, and formed a jet within the box. This water falling to the bottom of the box, came out of the ſpout Z.

It was found that the utmoſt exertion of an ordinary working man, could not make more than 60 revolutions of the handle in a minute; in which caſe the rope moved at the rate of about 16 feet per ſecond. With this velocity the quantity of water that came out of the ſpout Z, was about ſix gallons per minute: but it would have been

been impoſſible for the man to have worked at that rate for more than three or four minutes.

This machine may evidently be placed aſlant, viz. ſo as to convey the water from one place to another, which is not quite perpendicularly over the former. The ſame conſtruction and almoſt the ſame expence will adapt the machine to wells of different depths, though the effects will not be always the ſame.

More than one rope, or a broad band inſtead of a rope, might be adapted to this machine, for which purpoſe the wheels muſt have more than one, or a broad, groove, &c.

The greateſt diſadvantage of this machine is, that the rope does not laſt long. Its being always wet deſtroys it very ſoon.—In putting on the rope, care muſt be had to ſoke it well in water before it be ſpliced; otherwiſe it will either be too tight, or it will break.—A hair rope has been found to laſt longer than one of hemp.

The Mechanical Paradox.

The effect which ariſes from that curious property of non-elaſtic fluids, viz. from their preſſing upon equal bottoms, according to their perpendicular altitudes, without any regard to their quantities, has been commonly called the *hydroſtatical paradox*, and various machines, more or leſs complicated, have been conſtructed for the purpoſe of rendering it

ſtrikingly

ſtrikingly evident; but after the theoretical explanation which has been given of that property, it ſeems uſeleſs to employ more pages on the deſcription of ſuch machines. I ſhall, however, add one of the leaſt complicated conſtruction. This is repreſented in fig. 7. Plate XV. It is commonly called the *hydroſtatical bellows*.

It conſiſts of two thick oval boards, each about 16 inches broad and 18 inches long, joined by means of leather, to open and ſhut like common bellows, excepting that they move parallel to each other. A pipe B, about 3 feet high, is fixed into the bellows at *e*.

Let ſome water be poured into the pipe at *o*, which will run into the bellows, and ſeparate the boards a little. Lay three weights *b*, *c*, *d*, each weighing 100 pounds, upon the upper board; then pour more water into the pipe B, which will run into the bellows, and will raiſe the board with all the weights upon it; and if the pipe be kept full, until the weights are raiſed as high as the leather which covers the bellows will allow them, the water will remain in the pipe, and ſupport all the weights, even though it ſhould weigh no more than a quarter of a pound, and they 300 pounds; nor will all their force be able to cauſe them to deſcend and force the water out at the top of the pipe.

A man may ſtand upon the upper board, inſtead of the weights, and he may raiſe himſelf by pouring water into the pipe B; which will appear very wonderful

wonderful to unſkilled perſons; but the wonder will vaniſh, if it be conſidered that if the man raiſes himſelf one tenth part of an inch, the water muſt deſcend down almoſt the whole length of the pipe; ſo that the ſmall quantity of water in the pipe can balance the weight of the man, becauſe their velocities, or the ſpaces they muſt move through, are inverſely as their weights; which renders their momentums equal.

I ſhall not deſcribe the various ſorts of mills, or of other hydraulic engines, on three accounts principally, viz. firſt becauſe thoſe machines, though very uſeful, do not point out any new property of fluids, beſides what have been already explained; ſecondly, becauſe the deſcriptions of thoſe engines may be found in a variety of books, ſuch as dictionaries of arts and ſciences, tranſactions of learned ſocieties, treatiſes on mechanics, on hydroſtatics, &c. and 3dly, becauſe, by the inſertion of thoſe deſcriptions, this work would be ſwelled up to an enormous ſize.—The following machine is not very commonly known.

The Machine for Blowing, by means of a Fall of Water.

Wherever there is the conveniency of a fall of water, which is frequently the caſe in the vicinity of hills, mountains, &c. there a machine for blowing the fire of a furnace may be eaſily conſtructed; and

and it will it prove both uſeful and laſting, almoſt without any farther expence than that which attends the original conſtruction.

The dimenſions of ſuch machines muſt be ſuited to the circumſtances of the ſituation, ſize of the furnace, &c. but thoſe particulars may be eaſily derived from the general principles of the conſtruction, which I ſhall give in the words of Profeſſor Venturi, the gentleman who has given the beſt and moſt recent explanation of thoſe principles.

"Let BCDE, fig. 17. Plate XV. repreſent "a pipe, through which the water of a canal AB, "falls into the lower receiver MN. The ſides of "the tube have openings all round, through which "the air freely enters to ſupply what the water car"ries down in its fall. This mixture of water and "air proceeds to ſtrike a maſs of ſtone Q; whence "rebounding through the whole width of the re"ceiver MN, the water ſeparates from the air, "and falls to the bottom at XZ, whence it is diſ"charged into the lower channel or drain, by one "or more openings T, V. The air, being leſs "heavy than the water, occupies the upper part "of the receiver, whence, being urged through "the upper pipe O, it is conveyed to the "forge.

"I formed one of theſe artificial blowing engines "of a ſmall ſize. The pipe BD was two inches "in diameter, and four feet in height. When the "water

" water accurately filled the ſection B C, and all " the lateral openings of the pipe B D E C were " cloſed, the pipe O no longer afforded any " wind." (See the note in page 180 of this volume.)

" It is, therefore, evident, that in the open pipes " the whole of the wind comes from the at- " moſphere, and no portion is afforded by the de- " compoſition of water. Water cannot be decom- " poſed and transformed into gas, by the ſim- " ple agitation and mechanical percuſſion of its " parts. The opinions of Fabri and Dietrich " have no foundation in nature, and are contrary " to experiment.

" It remains, therefore, to determine the cir- " cumſtances proper to drive into the receiver " M N, the greateſt quantity of air, and to mea- " ſure that quantity. The circumſtances which " favour the moſt abundant production of wind, " are the following:

" 1. In order to obtain the greateſt effect from " the acceleration of gravity, it is neceſſary that " the water ſhould begin to fall at B C, with the " leaſt poſſible velocity; and that the height of " the water F B ſhould be no more than is neceſ- " ſary to fill the ſection B C. I ſuppoſe the ver- " tical velocity of this ſection to be produced by an " height or head equal to B C.

" 2. We do not yet know, by direct experi- " ment, the diſtance to which the lateral commu-

" nication

" nication of motion between water and air can ex- " tend itſelf; but we may admit, with confidence, " that it can take place in a ſection double that of " the original ſection with which the water enters " the pipe. Let us ſuppoſe the ſection of the pipe " B D E C, to be double the ſection of the water " at B C; and in order that the ſtream of fluid " may extend and divide itſelf through the whole " double ſection of the pipe, ſome bars, or a grate, " are placed in B C, to diſtribute and ſcatter the " water through the whole internal cavity of the " pipe.

" 3. Since the air is required to move in the " pipe O, with a certain velocity, it muſt be " compreſſed in the receiver. This compreſſion " will be proportioned to the ſum of the accele- " rations, which ſhall have been deſtroyed in the " inferior part K D of the pipe. Taking K D " equal to one foot and a half, we ſhall have a " preſſure ſufficient to give the requiſite velocity " in the pipe O. The ſides of the portion KD, as " well as thoſe of the receiver MN, muſt be ex- " actly cloſed in every part.

" 4. The lateral openings in the remaining " part of the pipe B K, may be ſo diſpoſed " and multiplied, particularly at the upper part, " that the air may have free acceſs within the " tube. I will ſuppoſe them to be ſuch, that " one-tenth part of a foot height of water " might be ſufficient to give the neceſſary ve-

“ locity to the air at its introduction through the apertures. (1)

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(1) “ All theſe conditions being attended to, and ſuppoſing the pipe B D to be cylindrical, it is required to determine the quantity of air which paſſes in a given time through the circular ſection K L. Let us take, in feet, $KD = 1{,}5$; $BC = BF = a$; $BD = b$. By the common theory of falling bodies, the velocity in K L will be $7{,}76 \sqrt{a + b - 1{,}4}$; the circular ſection $KL = 0{,}785\, a^2$. Admitting the air in K L to have acquired the ſame velocity as the water, the quantity of the mixture of the water and air, which paſſes in a ſecond, through K L, is $= 6{,}1\, a^2 \sqrt{a + b - 1{,}4}$. We muſt deduct from the quantity $(a + b - 1{,}4)$ that height which anſwers to the velocity the water muſt loſe by that portion of velocity which it communicates to the new air laterally and conſtantly introduced; but this quantity is ſo ſmall, that it may be neglected in the calculation. The water which paſſes in the ſame time of one ſecond through B C, is $= 0{,}4\, a^2 \sqrt{a + 0{,}1}$. Conſequently, the quantity of air which paſſes in one ſecond through K L, will be $= 6{,}1\, a^2 \sqrt{a+b-1{,}4} - 0{,}4\, a^2 \sqrt{a+0{,}1}$; taking the air itſelf, even in its ordinary ſtate of compreſſion, under the weight of the atmoſphere. It will be proper, in practical applications, to deduct one-fourth from this quantity; 1ſt, on account of the ſhocks which the ſcattered water ſuſtains againſt the interior part of the tube, which deprive it of part of its motion; and, 2dly, becauſe it muſt happen that the air in L K will not, in all its parts, have acquired the ſame velocity as the water.”

“ If

"If the pipe O do not diſcharge the whole "quantity of air afforded by the fall, the water "will deſcend at X Z; the point K will riſe in "the pipe, the afflux of air will diminiſh, and "part of the wind will iſſue out of the lower "lateral apertures of the pipe B K*."

The Anemometer, or Wind-gage.

The direction and the ſtrength are the two particulars which may be required to be aſcertained with reſpect to the wind.

The methods of determining the actual direction, by means of wind-vanes, or of the motion of clouds, &c. are too common and too obvious, to need any particular deſcription; but for the purpoſe of meaſuring the force of the wind, ſeveral inſtruments have been contrived; ſuch as a board faſtened to the rod of a pendulum, which ſhews the ſtrength of the wind by the angle to which the pendulum is cauſed to deviate from the perpendicular; ſuch alſo as a ſmall windmill, which, by the number of revolutions that are performed in a given time, gives an eſtimate of the force of the wind, &c. but amongſt all thoſe inſtruments, the moſt portable, leſs equivocal, and leſs complicated,

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* Venturi's Experimental Enquiry on the lateral communication of motion in fluids. Prop. VIII.

wind-gage, is one which was contrived by Dr. James Lind of Windſor: this is delineated in fig. 8. Plate XV. which is about one-half of the real, or more uſual, ſize of ſuch inſtruments.—Philoſophical Tranſactions, vol. 65, p. 353.

" This ſimple inſtrument conſiſts of two glaſs tubes, A B, C D, of five or ſix inches in length.* Their bores, which are ſo much the better always for being equal, are each about $\frac{4}{10}$ths of an inch in diameter. They are connected together like a ſyphon, by a ſmall bent glaſs tube *a b*, the bore of which is $\frac{1}{10}$th of an inch in diameter. On the upper end of the leg A B, there is a tube of latten braſs, which is kneed or bent perpendicularly outwards, and has its mouth open towards F. On the other leg C D is a cover, with a round hole G in the upper part of it, $\frac{2}{10}$ths of an inch in diameter. This cover, and the kneed tube are connected together by a ſlip of braſs *c d*, which not only gives ſtrength to the whole inſtrument, but alſo ſerves to hold the ſcale H I. The kneed tube and cover are fixed on with hard cement, or ſealing-wax. To the ſame tube is ſoldered a piece of braſs *e*, with a round hole in it, to receive the ſteel ſpindle K L, and at *f* there is juſt ſuch another piece of braſs ſoldered to the braſs hoop *g h*, which ſurrounds both legs of the inſtrument. There is a ſmall

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* " They ought to be longer, as in ſeveral caſes the " abovementioned length has been found inſufficient."

ſhoulder

ſhoulder on the ſpindle at *f*, upon which the inſtrument reſts, and a ſmall nut at *i*, to prevent it from being blown off the ſpindle by the wind. The whole inſtrument is eaſily turned round upon the ſpindle by the wind, ſo as always to preſent the mouth of the kneed tube towards it. The lower end of the ſpindle has a ſcrew on it; by which it may be ſcrewed into the top of a poſt, or a ſtand made on purpoſe. It alſo has a hole at L, to admit a ſmall lever for ſcrewing it into wood with more readineſs and facility. A thin plate of braſs, *k*, is ſoldered to the kneed tube about half an inch above the round hole G, ſo as to prevent rain from falling into it. There is likewiſe a crooked tube A B, fig. 9. to be put on occaſionally upon the mouth of the kneed tube F, in order to prevent rain from being blown into the mouth of the wind-gage, when it is left out all night, or expoſed in the time of rain. The force or *momentum* of the wind may be aſcertained by the aſſiſtance of this inſtrument, by filling the tubes half-full of water, and puſhing the ſcale a little up or down, till the o of the ſcale, when the inſtrument is held up perpendicularly, be on a line with the ſurface of the water, in both legs of the wind-gage. The inſtrument being thus adjuſted, hold it up perpendicularly, and turning the mouth of the kneed tube towards the wind, obſerve how much the water is depreſſed by it in one leg, and how much it is raiſed in the other. The ſum of the two is the height of a column of water which the wind is capable of ſuſtaining at that time; and every body that is oppoſed to that wind, will be preſſed upon by a force equal to the weight of a column of water, having its baſe equal to the ſurface that is expoſed, and its height equal to the altitude of the column of water ſuſtained by the wind in the wind-gage. Hence the force of the wind upon any body, where the ſurface oppoſed to it is known, may be eaſily found, and a ready compariſon may be made betwixt the ſtrength of one gale of wind and that of another, by knowing the heights of the columns of water, which the different winds were capable of ſuſtaining. The heights of the columns in each leg will be equal, provided the legs are of equal bores; otherwiſe the heights muſt be calculated accordingly.

" The force of the wind may likewiſe be meaſured with this inſtrument, by filling it until the water runs out at the hole G. For if we then hold it up to the wind as before, a quantity of water will be blown out; and, if both legs of the inſtrument are of the ſame bore, the height of the column ſuſtained will be equal to double the column of water in either leg, or the ſum of what is wanting in both legs. But if the legs be of unequal bores, then the heights muſt be calculated accordingly.

" On land this inſtrument may be left out expoſed all night, &c.; but at ſea it muſt always be held up by the hand in a perpendicular poſition, whether

whether it be uſed when only half-full of water, or when quite full; which laſt will be frequently found to be the only practicable method during the night.

" The uſe of the ſmall tube of communication *a b*, fig. 8. is to check the undulation of the water, ſo that the height of it may be read off from the ſcale with eaſe and certainty. But it is particularly deſigned to prevent the water from being thrown up to a much greater or leſs altitude than that which the wind can ſuſtain.

" The height of the column of water ſuſtained in the wind-gage being given, the force of the wind upon a foot ſquare is eaſily had by the following table, and conſequently on any known ſurface."

Height of the water in the gage.	Force of the wind on one foot ſquare in pounds avoirdupoiſe.	Common deſignations of ſuch winds.
Inches 12	62,500	
11	57,293	
10	52,083	moſt violent hurricane.
9	46,875	
8	41,667	very great hurricane,
7	36,548	great hurricane.
6	31,750	hurricane.
5	26,041	very great ſtorm.
4	20,833	great ſtorm.
3	15,625	ſtorm.
2	10,416	very high wind.
1	5,208	high wind.
0,5	2,604	briſk gale.
0,1	0,521	freſh breeze.
0,05	0,260	pleaſant wind.
0,025	0,030	a gentle wind.

When the height of the water is not exactly mentioned in the table, then that height may be ſeparated into ſuch parts as are mentioned in the table, and the ſum of the forces anſwering to ſuch parts will be the force of the wind correſpondent to the height in queſtion; thus, if the height of the water be 4,6 inches; then this height is equal to 4, plus

plus 0,5, plus 0,1, which parts are all in the table; therefore

		lbs.
4	inches	20,833
0,5	—	2,604
0,1	—	0,521

The ſum is 23,958, which expreſſes the force of the wind when the height of the water in the gage is 4,6 inches.

Any alteration that can uſually take place in the temperature of the water, makes no ſenſible difference in this inſtrument.

In froſty weather this gage cannot be uſed with common water. At that time ſome other liquor muſt be uſed, which is not ſo ſubject to freeze; and, upon the whole, a ſaturated ſolution of common ſalt in water is the moſt eligible: but in that caſe (ſince the ſpecific gravity of a ſaturated ſolution of ſalt is to that of pure water as 1,244 to 1) the forces which are ſtated in the preceding table muſt be multiplied by 1,244. Thus, if in the preceding example the ſaturated ſolution of ſalt had been uſed inſtead of water only, the force of the wind on a ſquare foot, would have been 29,8 pounds *.

The

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* When ſalt-water is uſed, the force of the wind, which is ſtated in the table, muſt be increaſed in the proportion of the

The Barometer.

The conſtruction of the barometer has been ſo often varied at different times, and by different ingenious perſons, that a deſcription of all its ſhapes and varieties would be endleſs; but it would at the ſame time be uſeleſs, ſince few of thoſe various conſtructions are really ſufficiently uſeful, either for the common purpoſe of indicating the variations of the gravity of the atmoſphere, or for the purpoſe of meaſuring altitudes.

As the uſual perpendicular movement of the mercury in the barometer, upon the whole, hardly amounts to two inches and a half, therefore the principal object of various ingenious perſons has been to extend the ſcale, ſo that very ſmall variations might be rendered apparent.

One of the methods by which this object has been accompliſhed, is repreſented in fig. 8. of Plate XVI.

A B is a glaſs tube about 5 or 6 feet long, open at its lower end, and having an enlargement CD at

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the ſpecific gravity of ſalt-water to that of common water; thus, uſing the preceding example, we muſt ſay, as 1 : 1,244 : : 23,958 to a fourth proportional, which muſt be found by multiplying the ſecond term by the third, and then dividing the product by the firſt term; but, the firſt term being unity, we need only multiply 23,958 by 1,244.

the height of between 28 and 31 inches above its lower extremity. This tube is filled with mercury as high as about CD, viz. the middle of the enlargement of its cavity; and the upper part of it, viz. from the ſurface C D of the mercury, to a certain place E, in the upper part G B of the tube, is filled with tinged ſpirit of wine; the remaining ſpace EB being a vacuum. F is a baſon containing quickſilver, wherein the lower end of the tube is immerſed.

When the mercury riſes in the barometer; for inſtance, one inch in the enlargement CD, it is evident that a certain quantity of ſpirit of wine muſt be forced by it into the part GB, which will fill much more than one inch length of the tube GB, firſt becauſe one inch altitude of the cavity CD contains ſpirit of wine enough to fill up ſome inches length of the tube GB; and 2dly, becauſe one inch perpendicular altitude of quickſilver is equivalent to ſeveral inches perpendicular altitude of ſpirit of wine. By this means a ſmall variation of the altitude of the mercury in CD, is indicated by a much more apparent variation of the altitude of the ſpirit of wine in GB.

Barometers, containing mercury and ſpirits, or mercury and water, or mercury and ſome other liquor, have alſo been made of ſeveral parallel tubes connected together in a zigzag way; but I need not detain my reader by a particular deſcription of ſuch barometers, ſince they are all much more imperfect

perfect than the ſimple ſtraight mercurial barometer. Their imperfections principally ariſe from the expanſion and contraction of the other fluid beſides the mercury, and from the vapour which being extricated from that other fluid, and occupying the upper part of the tube, counteracts in great meaſure the preſſure of the atmoſphere.

The elongation of the ſcale, or of the apparent motion of the barometer, has alſo been accompliſhed by inclining part of the mercurial barometer. Thus, in fig. 9. Plate XVI. the tube is ſtraight from the baſon B, to the altitude A, viz. about 28 inches, but the reſt, A C, is inclined to the horizon.

Now, as the ordinary perpendicular motion of the quickſilver amounts to about three inches, which is equal to AD; therefore, when it moves not perpendicularly from A to D, but obliquely through A C, it muſt run all the way from A to C, in order to attain three inches of perpendicular altitude; ſo that if the part A C be 12 inches long, viz. four times as long as the part AD, then, whilſt the mercury in a ſtraight barometer riſes one inch, in this ſlant barometer, it will run along four inches length of the part A C; and of courſe the ſmall alterations of the preſſure of the atmoſphere are thereby rendered more apparent. Yet this ſlant barometer is by no means ſo accurate as a ſtraight one; and the cauſes of its inaccuracy principally, are the obliquity of the ſurface of the mercury in the

the part A C, the difficulty of obtaining, or of knowing, when the part A C is perfectly ſtraight, and the want of freedom in the motion of the quickſilver, which ariſes from its attraction towards the glaſs, and which increaſes with the increaſe of the obliquity of the part A C.

Barometers are alſo made to move circular indexes; they have likewiſe been made with an horizontal elongation at the lower part of the tube; always for the purpoſe of extending the ſcale. But all thoſe conſtructions are attended with conſiderable imperfections; ſo that, upon the whole, the ſtraight mercurial barometer is the beſt. Upon ſuch a barometer for common purpoſes, the altitude may be commodiouſly read off to the exactneſs of one-hundredth part of an inch; and on thoſe which are made for meaſuring altitudes, as mountains, &c. it may generally be read off within the 500th part of an inch.

I need not deſcribe the ornamental part of the common barometers, which is varied by the fancy of every maker; but a complete one is ſhewn by fig. 14. Plate XVI.; two things, however, deſerve to be mentioned, viz. the more uſual conſtruction of the lower part, or of the ciſtern; and the nature of the nonius, which (in the beſt conſtruction) is affixed to the index for the purpoſe of indicating the ſmall parts of an inch.

The lower part of the tube is ſometimes bent and enlarged, as is ſhewn by fig. 10. of Plate XVI.

in

in which conſtruction, when the barometer is to be removed from one place to another, the inſtrument is turned gently upſide down, and the mercury filling the whole tube, comes not higher than the curvature A; but when the barometer is ſet ſtraight up againſt a wall in the uſual way, then the quickſilver deſcending a little way from the cloſed upper end of the tube, fills the part A B, and riſes a little way within the enlarged part B; which in fact is the ciſtern of the barometer. Sometimes the barometers are made with an open ciſtern, in which caſe they act well, but are not portable, unleſs they be carried ſtraight up, and very gently, from one place to another.

The moſt portable barometers of the common ſort, have a little bag made of a piece of bladder, tied round their lower extremity. This bag and tube are filled with mercury, and no part of that mercury is expoſed to the atmoſphere; but the atmoſphere preſſes upon the outſide of the bag, which anſwers the ſame purpoſe. To thoſe barometers a ſcrew S, fig. 13. Plate XVI. is affixed to the frame, which, when the barometer is to be carried from place to place, is ſcrewed upwards by applying the hand to the milled head T, by which means the preſſure of the ſcrew againſt the bag, puſhes the mercury into the tube, fills up the whole length of the tube, and renders the inſtrument quite portable.

On reflection it will appear, that, according to the

the above-mentioned conſtruction of ciſterns, when the mercury riſes in the tube, it muſt fall in the ciſtern; in conſequence of which the altitude of the mercury ſhould always be reckoned from the ſurface of the mercury in the ciſtern; this, however, excepting in barometers for meaſuring altitudes, is in general not taken notice of; ſince the difference is not great.

The principle of what is commonly, though improperly, called *nonius*, may be better explained by means of an example. This curious contrivance is of great uſe; and in fact it has been applied to a great variety of philoſophical, and principally of aſtronomical, inſtruments *.

Suppoſe that a ſcale, as AB, fig. 11. Plate XVI. is divided in inches only, and that the parts of an inch (for inſtance, the quarters) be required to be meaſured by means of a nonius: CD is the nonius, viz. a little ſcale, moveable over, or along, the ſide of the ſcale AB. The conſtruction of this nonius is ſuch, that the diſtance CD, which is equal to three inches, is divided into four equal parts;

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* "This method was publiſhed by Peter Vernier (a " gentleman of Franche Comté) at Bruſſels, in the year " 1631; and which, by ſome ſtrange fatality, is moſt un" juſtly, although commonly, called by the name of *Nonius*; " for *Nonius*'s method is not only very different from that of " *Vernier*, but much leſs convenient." Robertſon's Navigation, B. V. §. 219.

whereas, on the ſcale, the ſame length is divided into three equal parts; ſo that the diviſions of the nonius are to thoſe of the ſcale as 4 to 3. Therefore the parts, or diviſions, of the nonius are ſhorter than the diviſons of the ſcale, *viz.* each part of the nonius muſt be equal to three-quarters of each diviſion of the ſcale; hence the firſt diviſion of the nonius, which lies between 0 and ¼, is one-quarter of an inch ſhorter than the next diviſion of the ſcale; the ſecond diviſion of the nonius is half an inch diſtant from the next diviſion of the ſcale; and the third diviſion of the nonius is three-quarters of an inch diſtant from the next diviſion (meaning always towards the right-hand) of the ſcale.

Now, when I am to meaſure the diſtance E F, by the application of the ſcale, I find it equal to four inches; but if I want to meaſure the diſtance E G, the ſcale will ſhew that it is more than four inches, but not how much more; now, in order to find how much more than four inches that diſtance EG is, I move the nonius forward until its edge D coincides with G. (Here the diſtance E G is not placed cloſe to the ſcale and nonius, only to avoid confuſion) and in that caſe, I find that the third diviſion of the nonius coincides with one of the diviſions of the ſcale; but that diviſion of the nonius, as has been ſhewn above, was three quarters of an inch diſtant from the next diviſion of the ſcale; therefore the nonius has now been advanced three quarters of an inch, as is ſhewn by fig. 12. and of of courſe the length EG is four inches and three-quarters.

What has been ſaid of this nonius may be eaſily applied to explain the principle of every other nonius; viz. as by this nonius we have the quarters of an inch, becauſe the ſame ſpace of three inches is divided into three equal parts on the ſcale, and into four equal parts on the nonius; ſo we may have the tenths of an inch if the ſame ſpace of 9 inches be divided into 10 equal parts on the nonius; ſo alſo we may have the hundredths of an inch, if the ſame ſpace, which is divided into 9-tenths of an inch on the ſcale be divided into 10 equal parts on the nonius; and ſo forth.

The barometers for meaſuring mountains, or altitudes in general, muſt be made with much greater accuracy than thoſe of the common ſort; their ſcale muſt be longer; the mercury in the ciſtern muſt be raiſed by means of a ſcrew always to the ſame mark, in order that the diviſions of the ſcale may indicate the real altitudes of the ſurface of the mercury in the tube above that of the mercury in the ciſtern. They alſo muſt be furniſhed with a ſtand capable of ſupporting them in a perpendicular ſituation; for otherwiſe they cannot be ſuſpended ſtraight up on the ſides of mountains; and great care muſt be had to render ſuch inſtruments as portable and as ſecure as poſſible.

Various contrivances have been made and executed for the attainment of ſuch objects. The lateſt and perhaps the beſt, but by no means the ſimpleſt, was made by Mr. Haas; I ſhall, however, briefly deſcribe the conſtruction of the portable barometers contrived and conſtructed by the late very ingenious philoſophical inſtrument-maker, Mr. Jeſſe Ramſden, which have been uſed by various philoſophical gentlemen, and eſpecially by Colonel Roy in his numerous meaſurements. Fig. 20. and 21. of Plate XVI. exhibit a barometer of this conſtruction, both in the ſituation proper for obſervation, and packed up.

“ The principal parts of this inſtrument are a
“ ſimple ſtraight tube, fixed into a wooden ciſtern
“ A, which, for the conveniency of carrying, is
“ ſhut with an ivory ſcrew B, and that being re-
“ moved, is open when in uſe. Fronting this
“ aperture is diſtinctly ſeen the coincidence of the
“ gage-mark, with a line on the rod of an ivory
“ float, ſwimming on the ſurface of the quickſilver,
“ which is raiſed or depreſſed by a braſs ſcrew C at
“ the bottom of the ciſtern. From this, as a fixed
“ point, the height of the column is readily mea-
“ ſured on the ſcale D attached to the frame, al-
“ ways to $\frac{1}{500}$ part of an inch, by means of a no-
“ nius E, moved with rack-work. A thermo-
“ meter F is placed near the ciſtern, whoſe ball
“ heretofore was uſually incloſed within the wood-
“ work, a defect that hath been ſince remedied.
“ The three-legged ſtand, ſupporting the inſtru-
“ ment when in uſe, ſerves as a caſe for it when

"inverted and carried from place to place, fig. 21. "Two of theſe barometers, after the quickſilver "in them hath been carefully boiled, being ſuffered "to remain long enough in the ſame ſituation, to "acquire the ſame temperature, uſually agree in "height, or rarely differ from each other more "than a few thouſandth parts of an inch*."

The Air-Pump.

The *air-pump* is an inſtrument which ſerves to draw, or pump, the air out of any veſſel which is properly adapted to it. This noble engine is one of the principal inſtruments which have, ſince the middle of the 17th century, contributed to the rapid advancement of natural philoſophy, by affording the means not only of verifying what had been advanced and conjectured by ſeveral learned perſons concerning the atmoſphere; but likewiſe of trying a great many experiments, and of aſcertaining a vaſt number of new and intereſting facts.

The original principle or conſtruction of the air-pump is ſimilar to that of the common water-pump which we have already deſcribed; excepting that the parts of the air-pump muſt be executed with very

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* Philoſophical Tranſactions, vol. 67. p. 658.

very great accuracy, for the purpoſe of intercepting the paſſage of the air, where that is not wanted, and which, on account of the preſſure of the atmoſphere and the ſubtlety of the air, cannot be well intercepted, without the utmoſt mechanical accuracy.

The firſt conſtruction of the air-pump was very imperfect, but a variety of improvements gradually removed its imperfections, and multiplied its varieties, ſo that at preſent there are various ſorts of air-pumps in uſe, which are more or leſs complicated, more or leſs effectual in exhauſting, and more or leſs expenſive. The hiſtory of moſt of its improvements and ſhapes, makes a very entertaining article in various books, and eſpecially in the Encyclopædia Britannica, under the article Pneumatics; but ſeveral of thoſe improvements need not be noticed at preſent, ſince they have been ſuperſeded by better contrivances. The deſcription of the particular conſtructions, at leaſt of the moſt uſeful, may be found in the above-mentioned article, or in other works that are mentioned in the note. We ſhall only deſcribe the principle of the ſimpleſt pump which is now in uſe, for the purpoſe of giving the ſtudent a clear idea of the principal parts of that exhauſting engine, and ſhall then ſubjoin the deſcription of an improved one which was lately contrived and executed by Mr. Haas, eſpecially as that conſtruction has not, as far as I know, been deſcribed in any other publication*.

Fig.

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* The air-pump was firſt invented by Otto Guericke, a gentleman of Magdeburgh in Germany, about the year 1654. (Schottus. Mech. Hydraulico-Pneum.) Soon after, Guericke's contrivance was imitated and greatly improved, in England, by the celebrated and indefatigable Mr. Boyle (ſee his works), who was aſſiſted by ſeveral eminent perſons, and eſpecially by Dr. Hook, a gentleman of a moſt inventive mechanical genius. But the want of ſkill in the then exiſting workmen, and the deficiency of ſeveral articles, ſtill rendered the air-pump a very imperfect inſtrument, until Mr. Hawkeſbee produced an improved and elegant engine of that ſort, which has been copied by many artiſts here and elſewhere, and is even at preſent in uſe amongſt philoſophers. (See the deſcription of it in Dr. Deſagulier's Philoſophical Works.) Another pump, ſomewhat different, was alſo conſtructed by Graveſande. (See his Courſe of Philoſophy.) But a very capital improvement of the air-pump was made in almoſt all its parts, by the late famous engineer, Mr. John Smeaton; (ſee his deſcription in the 47th vol. of the Philoſophical Tranſactions); and a well-made pump of that ſort, undoubtedly, is one of the beſt now extant; yet, after the interval of about 25 years, this conſtruction was followed by ſeveral other contrivances, ſome of which are certainly ſuperior to it. The beſt of thoſe latter contrivances are, a pump by Mr. Haas; (ſee its conſtruction in the 73d vol. of the Philoſophical Tranſactions); an air-pump by Mr. Prince of Boſton in America; (Encyclopædia Britannica, article Pneumatics); one by Mr. Cuthbertſon, an eminent philoſophical-inſtrument

maker,

Fig. 18. of Plate XVI. exhibits the ſimpleſt ſort of air-pump. AB is the braſs barrel, which is repreſented as being tranſparent for the purpoſe of ſhewing the conſtruction of the internal parts. The inſide of the barrel is as perfectly cylindrical as can be made, and very ſmooth. The barrel is open at top, or if furniſhed with a cover, that cover is perforated for the paſſage of the rod F G, and of the air. The bottom B of the barrel is accurately cloſed by a flat piece of braſs, excepting a ſmall hole, which paſſes through the ſaid piece, and communicates with the cavity of the glaſs receiver D, which is cemented into the piece C, and out of which the air is to be pumped. The ſmall hole in the flat bottom of the barrel is covered by a ſlip of oil-ſilk, which is ſtrained over it; whence it appears,

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maker, at preſent in London; (Encyclopædia Britannica, article *Pneumatics.*) A very good improvement of the air-pump was made in France by M. Lavoiſier, and other ſcientific perſons, which rendered that engine capable of exhauſting to a very great degree; but it is ſaid, that that conſtruction is difficultly executed, and eaſily put out of order.

The ſixth vol. of the Tranſactions of the Royal Iriſh Academy contains the deſcription of an air-pump, contrived by the Rev. James Little, of Lacken, in the county of Mayo. This paper, beſides the particular deſcription of the inſtrument, contains ſeveral good obſervations on the general ſubject of air-pumps, and apparatus.

that

that air may paſs from the receiver D, into the barrel; but it cannot go from the latter into the former. E is a piſton, viz. a ſolid piece of braſs, covered over with leather ſoked in oil, or other greaſy matter, which fitting the cavity of the barrel very accurately, may be moved up or down all along the barrel, by means of the rod F G, without admitting any air between the ſurface of the barrel and that of the piſton. But there is a hole, indicated by the dotted lines at E, which paſſes through the piſton, and has its upper end covered with a ſtrained ſlip of oil-ſilk, ſimilar to the valve at the bottom B of the cylinder. The valve in the piſton permits the air's paſſage from E to G, but not the contrary way. If the hand be applied to the handle F, and the piſton be moved alternately up and down the cylinder, the veſſel D will thereby be gradually exhauſted of air, and the proceſs of it is as follows:

When the piſton is drawn upwards, the ſpace between the lower part of it and the bottom of the cylinder is enlarged, and the air in it is rarefied; whereas the air in the receiver D is denſer than that; therefore the elaſticity or expanſive property of this air preſſes againſt the lower part of the oil-ſilk at the bottom of the cylinder, more than the air which is within the cylinder preſſes upon the upper ſide of it; hence part of the air of the veſſel D paſſes into the barrel, and of courſe the quantity of air in D is diminiſhed. Then, by depreſſing the piſton, the quantity of air which is between it and the bottom of the piſton is condenſed; hence it preſſes againſt the lower ſide of the valve G, more than the atmoſpheric air preſſes on the upper ſide of the ſame; therefore the greateſt part of that air paſſes through that valve into the atmoſphere. When the piſton is drawn upwards the ſecond time, the like effect takes place, and the air of the veſſel D is diminiſhed a little more*. Thus, by repeating the movement of the piſton, the veſſel D is gradually exhauſted of air to a certain degree, which is the utmoſt limit of the pump's exhauſting power; and that degree is expreſſed by the proportion which the air that laſtly remains in the veſſel D, bears to that which was at firſt in it. Thus, if the remaining air is one-tenth part of the original quantity, the pump is ſaid to have rarefied the air ten times; for, in fact, the remaining quantity of air in D, fills up ten times the ſpace which it occupied before the exhauſtion.

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[*] It will be eaſily comprehended, that if the valves in the piſton and at the bottom of the barrel could be opened with the utmoſt freedom, the quantity of air, which remained in the veſſel D, after every ſtroke of the piſton, would be to that quantity which was in it, previous to that ſtroke, as the capacity of the veſſel D is to the ſum of the capacities of that veſſel, and of the barrel.

A more

A more particular examination of the parts as well as operations of this pump, will point out the powers, the defect, and the improvements of air-pumps in general.

As the capacity of the barrel is generally ſmall in proportion to that of the veſſel, out of which the air is to be exhauſted in ſeveral experiments, the exhauſtion will proceed but ſlowly; therefore, in order to expedite the operation, pumps have been made with two barrels, which are moved alternately by means of a wheel with a handle, and racks affixed to the rods of the piſtons. Both barrels communicate with the ſame receiver, and the exhauſtion goes on as quick again as when one barrel is uſed.

The receiver cemented to the piece B C, at the bottom of the barrel, cannot be adapted to a great variety of experiments; therefore, inſtead of that, the barrel or barrels have been made to communicate with the ſame duct which opens in the middle of a pretty large and flat metal plate. Then a glaſs receiver of any required ſize, within certain limits, is placed with its aperture upon that plate, and is exhauſted, &c.—In order to prevent the admiſſion of air, between the edge of the receiver and the plate of the pump, it was formerly uſed to interpoſe a piece of wet leather, which, however, was found to be prejudicial on ſeveral accounts; hence the leather is now ſeldom uſed; but the edges of the receiver, as alſo the ſurface of the plate, are ground ſo very flat and ſmooth, that when the receiver is placed upon the plate, no air can paſs through, eſpecially if the leaſt film of oil be interpoſed, or be placed on the outſide of the edge of glaſs.

Both thoſe improvements, viz. the double barrel, and the plate, are ſeen in fig. 17. Plate XVI.

By inſpecting fig. 18. Plate XVI. it will alſo be eaſily underſtood, that when the air which remains within the veſſel D, is ſo far rarefied as not to have force ſufficient to open the valve at the bottom of the barrel, then the pump cannot exhauſt the veſſel any farther. This effect is alſo partly produced by the air which remains between the piſton and the bottom of the barrel, when the piſton is down. Now in order to avoid theſe inconveniences, ſeveral contrivances have been made, and it is the different nature of thoſe contrivances that forms the variety of thoſe air-pumps which have been mentioned above.

Mr. Haas's laſt air-pump (for this is not the ſame as was contrived by the ſame perſon ſome time ago, and which is deſcribed in the 73d vol. of the Philoſophical Tranſactions) is ſhewn in Plate XVI. fig. 2. and 5. The wooden frame of the machine is ſufficiently apparent in fig. 2. There are two barrels in it, which by turning the handle H, round the axis A, about one turn and a half one way, and then as much the other way, are worked alternately; for within the wooden part

BB, there is on the axis A, a wheel with teeth, which catch into the teeth of the racks, which are affixed to the rods of the piſtons.

The two barrels communicate with a common duct, which opens in the middle of the Plate P. This plate is firmly fixed upon a wooden pillar that proceeds from the ſtand or pedeſtal of the machine. O, O, at the lower part of the machine, are two veſſels affixed to the ends of the barrels; and their office is to receive the oil which gradually paſſes from the inſide of each barrel through the valve at the bottom.

Fig. 2. is one-eighth of the real ſize; and fig. 5. which exhibits a ſection of one of the barrels, is one-fourth of the real ſize.

At the bottom V of the barrel, there is a valve which opens outwards, viz. the air may be forced from the inſide of the barrel into the atmoſphere, but cannot go the contrary way.

The form of the piſton is pretty well indicated by the figure. It conſiſts of two pieces of braſs ſcrewed together, and holding between them circular pieces of leather, the edges of which rub againſt the cavity of the barrel. There is a valve in the piſton, through which the air may paſs from the upper part of the barrel into the lower, but not *vice verſa*. The rod of the piſton is quite ſmooth and cylindrical; it paſſes through, what is called, a collar of leathers, viz. through a hole made in many pieces of leather, which are contained in in a braſs box Z, on the top of the barrel.[*] Several holes are ſeen towards the upper part of the barrel, which communicate with a cavity, indicated by two dark lines, that runs all round the upper part of the barrel, and communicates with the duct D of communication with the plate of the machine.

When the piſton is drawn upwards, the air may paſs, though not very freely, from the upper to the lower part of the barrel, through the valve in the piſton; but when the piſton is raiſed ſo high, as that its lower ſurface be higher than the abovementioned holes, then the air from the receiver, which ſtands on the plate, coming through the duct D, may freely paſs into the barrel; for in that caſe there is neither valve nor any thing elſe that obſtructs its paſſage. Then on depreſſing the piſton, the air which has entered the barrel being compreſſed towards the lower part of the barrel, will be forced out of it through the valve at V. It is owing to the freedom with which the air can paſs from the receiver which ſtands on the plate, into the barrel, that this pump rarifies to a very conſiderable degree.

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[*] Theſe leathers as well as thoſe of the piſton, are well ſoked in hog's lard (ſome workmen ſoke them in oil and tallow). The latter fit the barrel, and the former fit the outſide of the piſton rod, ſo well as not to allow the paſſage of air.

It will appear on the leaſt reflection, that no pump can poſſibly remove all the air from any receiver; for the quantity of air which is expelled at each ſtroke of the piſton, is only a portion of what was in the receiver previous to that ſtroke; and therefore a much greater quantity of air ſimilar in denſity to that which was laſt expelled, muſt remain in the receiver. So that a great degree of rarefaction, but not a complete exhauſtion, is all that can be expected from the beſt pump; whereas the torricellian vacuum is much more complete than what is made by an air-pump.

When a pump of the common ſort rarefies the air of a receiver 200 or 160 times, it may be conſidered as a very good inſtrument of the kind. The very beſt pumps now extant, will rarefy the air 600 or even 800 times; but I am unwilling to ſtate the utmoſt effect of thoſe conſtructions; ſince a very trifling difference generally produces a conſiderable alteration in the reſult. The pump being recently put together, the valves being more or leſs ſtrained, the want of a due quantity of oil, between the moving parts of the engine, and various other particulars, render the pump more or leſs capable of rarefying the air of a receiver; and generally they rarefy to a great degree at firſt, but ſoon loſe that power.

The various methods of eſtimating the quantity of air which remains in the receiver after a certain action

action of the pump, or of meaſuring the rarefaction, will be ſhewn in the ſequel.

The glaſs receivers for an air-pump are of different ſizes, according to the nature of the experiments. Some of them are open at top, and to their upper aperture there is ſometimes applied a flat braſs plate, which is ground very ſmooth, or a ſocket is cemented; to which plate or ſocket various apparatuſes are affixed.

Sometimes the receivers are not ſet immediately on the plate of the pump, but they are ſet on another plate, which has a pipe with a ſtop-cock, that may be ſcrewed into the centre of the principal plate P. With this apparatus the air of the receiver may be rarefied as well as if the receiver ſtood upon the principal plate; and when that is done, by turning the ſtop-cock, and unſcrewing it from the middle of the principal plate, that receiver, having the air rarefied, may be removed together with the ſmall plate, and leave the pump ready for other experiments. This auxiliary plate, with its pipe and ſtop-cock, is commonly called a *transferrer*. See fig. 19. Plate XVI.

Of the various experiments which are uſually performed with the air-pump, and which are deſcribed in almoſt all the works on Natural Philoſophy, I ſhall briefly deſcribe a few only, as they will be quite ſufficient to indicate the general mode of making ſuch experiments.

Place

Place the glaſs receiver upon the plate P of the pump, as appears at fig. 2. taking care that both the edge of the receiver and the plate, be quite clean, and ſmearing the former with a very ſmall quantity of oil; then work the pump by turning the handle H of the machine alternately as far as it will go one way, and as far as it will go the other way. After a few ſtrokes you will find, upon trial, that the glaſs receiver adheres very firmly to the plate; for as the air is partly withdrawn from the inſide of the receiver, the preſſure of the atmoſphere on the outſide becomes manifeſt. The adheſion of the receiver to the plate increaſes in proportion as you continue to work the pump.

There is, in every air-pump, a ſcrew-nut on the duct of communication between the barrel and the receiver; which may be opened occaſionally, in order to let the external air enter the cavity of the receiver: ſo that if, in the above-mentioned caſe, this ſcrew-nut be opened, the air will ruſh in with an audible noiſe; in conſequence of which the adheſion of the receiver to the plate will be removed.

Under ſuch a receiver, or other receivers of different forms, a variety of things may be placed, and on rarefying the air, different effects will take place; but in deſcribing thoſe experiments, it will be ſufficient to ſay that certain effects are produced by certain ſubſtances *in vacuo*, or in the exhauſted receiver; meaning ſuch a vacuum as may be produced

duced by the air-pump; for a more perfect vacuum is always denominated the *torricellian vacuum*.

An exhauſted receiver does not appear different from what it does before the exhauſtion. Objects may be ſeen in it and through it, juſt as well in one caſe as in the other.

A lighted candle placed under the receiver of the pump will go out after a few ſtrokes of the piſton, and the ſmoke will be ſeen to deſcend; there being not air enough to ſupport it.

Animals die ſooner or later in the receiver of the air-pump. Inſects die lateſt in it, viz. after the lapſe of ſome hours. A dog, a cat, a rabbit, a mouſe, a bird, &c. begin to ſhew ſigns of uneaſineſs after a few ſtrokes of the piſton; the uneaſineſs, the quickening of the reſpiration, and the panting for want of air, increaſe gradually; vomiting, bleeding at the mouth and noſtrils, loſs of ſtrength, and ſwelling of the body, ſucceed; but all thoſe diſagreeable ſymptoms laſt not many minutes; for death ſoon cloſes the ſcene.

If previous to their death, air be admitted into the receiver, by opening the ſcrew-nut, the animals generally revive, provided the rarefaction has not broken any vital part.

If water be placed in a glaſs under the receiver of the pump, on working the machine, the water will at firſt appear full of air-bubbles, then thoſe air-bubbles enlarge, and coming out of the water, give it it the appearance of boiling. By rareſying the air, and of courſe removing the preſſure of the atmoſphere from the ſurface of the water, the air which is uſually contained in it is expanded in virtue of its elaſticity, and eſcapes from the water, which eſcape gives the appearance of boiling; for the water does not acquire any heat by it.—The like thing happens with ſeveral other fluids. If fiſhes be contained in the water, the rarefaction of the air kills them, and breaks their air-bladders. Even the minute inſects that are frequently ſeen in vinegar, are deprived of life if the vinegar be expoſed to the exhauſtion of the air-pump.

Shrivelled fruit, under the receiver, are generally ſwelled by the exhauſtion, and appear very plump, whilſt they remain in it.

A bladder, containing a very ſmall quantity of air, and having its neck tied up, when placed under the receiver, will, on exhauſting the receiver, ſwell up and appear quite full; the reaſon of which is, that when the preſſure of the atmoſphere is removed from the outſide of the bladder, the internal air expands itſelf.

Fig. 4. of Plate XVI. repreſents a little machine conſiſting of two little ſets of mill-ſails, *a* and *b*, which are of equal weights, are unconnected with each other, and turn with equal freedom upon their axes. Each ſet has four thin ſails, fixed into the axis; thoſe of the mill *a* have their planes perpendicular to the axis, thoſe of *b* are parallel to their

their axis; in conſequence of which when the mill *a* turns round in common air, it is little reſiſted by the air, whereas the other is reſiſted in a conſiderable degree. There is a pin in each axle near the middle of the frame, which goes quite through the axle, and ſtands out a little on each ſide of it; upon theſe pins, the ſlider *d* may be made to bear, and ſo hinder the mills from going, when the ſtrong ſpring *c* is ſet or bent againſt the oppoſite ends of the pins.

This little machine ſerves to ſhew the reſiſtance which air offers to the motion of bodies, which reſiſtance is proportionate to the ſurface that the body preſents directly before the air.

For this purpoſe the above-mentioned little machine, with the ſprings bent and ſet upon the axles, is ſituated upon the plate of the pump, and a receiver is placed upon it; but this receiver muſt have a ſocket, with a ſet or collar of leathers, cemented to its upper aperture, and a long wire muſt paſs through a hole in the leathers, like the rod of the piſton in fig. 5; and it muſt be ſo ſituated that the wire of the receiver may be puſhed down exactly upon the ſlider *d*, and diſcharge it from the pins; in conſequence of which the mills being impelled by the ſpring, will be cauſed to turn round. Now if this operation be performed when the receiver is full of air, it will be found that the mill *a* will turn round much longer than the other, for it meets with leſs reſiſtance; but if the ſame operation be performed when the receiver is exhauſted, then the mills will be found to turn for a much longer time, and will ſtop both at the ſame time.

The like thing is ſhewn by the deſcent of heavy bodies. There is a ſmall apparatus fitted to a braſs plate, which is to be ſituated on the upper aperture of a tall receiver. See fig. 7. of Plate XVI. It conſiſts of wire that paſſes through a collar of leathers, and has an hooked termination. There is alſo another wire *a*, which has a moveable flap hinged to its lower extremity. The flap being placed horizontally, may be reſted upon the hooked projection of the central wire *b*; then, by turning the wire *b* round its axis, the above-mentioned flap is diſengaged from the hooked projection, and drops in a perpendicular direction.

This mechaniſm is generally called *the guinea and feather apparatus*; becauſe a guinea and a feather, or different bodies of diſſimilar ſpecific gravities, are uſually placed upon the above-mentioned flap whilſt horizontal; and may be dropped from it, by turning the wire *b*. It appears that a guinea and a feather, or any other bodies, will arrive at the bottom of the veſſel, or will ſtrike the plate of the pump, at different times when the receiver is full of air; but preciſely at the ſame time, when the receiver is exhauſted; in that caſe, there being nothing in the receiver to reſiſt them, and their gravities being proportionate to their quantities of matter. See page 59 and 60 of vol. 1.

Place the glaſs, AB, fig. 1. Plate XVI. open at both ends, upon the plate of the pump over the hole, &c. and place your hand flat and cloſe to the upper aperture B of it. On exhauſting that glaſs, you will find that the hand is preſſed with a weight which increaſes in proportion as you continue to work the pump, and the adheſion is ſo great, that the hand cannot be removed, unleſs the ſcrew-nut be opened, and the air let into the glaſs.

The cups which are uſed by ſurgeons for bleeding, are often applied to the fleſh, by means of an exhauſting ſyringe, which is nothing more than a ſmall barrel with piſton and valves, exactly like the one deſcribed in page 468. This ſyringe is ſcrewed to the neck of the cup, whilſt the oppoſite and much larger aperture of the cup is applied to the ſurface of the body, &c.

If inſtead of applying the palm of the hand, you tie a piece of bladder over the aperture B of the above-mentioned glaſs, on working the pump, which removes the preſſure from the under part of the piece of bladder, the preſſure on the external part of it will become very manifeſt; for the bladder will be hollowed by it, and at laſt it will be broken with conſiderable noiſe.

Fig. 3. Plate XVI. repreſents a braſs machine, conſiſting of three pieces, A, B, C; which ſerves to ſhew the preſſure of the atmoſphere in a very ſtriking manner. A and B are two hemiſpherical

cups,

cups, which, when joined together, form a globe, the cavity of which communicates with the atmoſpherical air, through the pipe E, when the ſtop-cock D is open, otherwiſe it is abſolutely cloſed *.

Join the two hemiſpheres; ſcrew the end of the pipe E, into the centre hole of the plate of the air-pump, and open the ſtop-cock D. In this ſituation work the pump ſo as to exhauſt the globe A B; then ſhut up the ſtop-cock D, unſcrew the pipe E, with the globe from the pump, and ſcrew the piece C upon the pipe E. The globes now being exhauſted, the preſſure of the atmoſphere will force the two hemiſpheres, A and B, very powerfully againſt each other; ſo that if two ſtrong men, applying their hands, one at the upper ring A, and the other at the lower ring C, endeavour to ſeparate them, they will find it very difficult; for if the diameter of the hemiſpheres be four inches, there will be required a force equal to little leſs than 200 pounds to pull them aſunder. If the globe, thus exhauſted, be ſuſpended by either of the rings to an hook within the receiver of an air-pump, and that receiver be exhauſted, the

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* A wet leather, having a hole in its middle, is generally placed between the two hemiſpheres, in order to cloſe the aperture more effectually; but when they are well made, and their edges are ground properly, a little oil ſmeared over the edges is quite ſufficient for the purpoſe.

two hemiſpheres will ſeparate immediately; ſhewing, in a moſt convincing manner, that they adhered to each other merely in conſequence of the preſſure of the atmoſphere.

If you place a barometer under a tall glaſs receiver of the air-pump, and rarefy the air by working the pump, you will find that the quickſilver deſcends gradually in the tube of the barometer; for as the quickſilver is kept up in the barometer by the preſſure of the atmoſphere on the ſurface of the quickſilver of the ciſtern, and its altitude is proportionate to that preſſure, therefore, according as the preſſure is diminiſhed, ſo the quickſilver deſcends in the tube. Now, from what has been ſhewn above in chap. VIII. it appears, that if the preſſure upon the ciſtern of the barometer be reduced to one half, the height of the mercury in the tube will alſo be reduced to one half; if that preſſure be reduced to one quarter of its original quantity, then the altitude of the mercury in the tube will likewiſe be reduced to one quarter of the original altitude; in ſhort, the altitude of the mercury in the tube of the barometer under the receiver of the pump, is an exact meaſure of the preſſure on the ciſtern, or of the quantity of elaſtic fluid that remains in the receiver, or of the elaſticity of that fluid; for the latter is proportionate to the former. Hence the barometer becomes a very good gage of the power of the air-pump, or of the degree of rarefaction; for the altitude of the mercury in its tube, is to the altitude of the ſame at any period of the rarefaction, as the entire capacity of the receiver, or as the air of the uſual denſity, is to the denſity or quantity of the air in the receiver at that period; ſo that if the mercury in the barometer ſtood originally at 30 inches height, and, after working the pump a certain time, it ſtands at the altitude of one inch, the concluſion is, that the air within the receiver has been rarefied 30 times, or that the air which remains in the receiver is the 30th part of that which was in it before the working of the pump, ſince one inch is the 30th part of 30 inches. Thus alſo, if the mercury in the barometer is found to ſtand one tenth of an inch above that of the ciſtern, the concluſion is, that the air has been rarefied 300 times, &c.

Upon this principle three gages have been conſtructed, viz. *the ſhort barometer gage, the long barometer gage, and the ſyphon gage.*

The ſhort barometer gage is nothing more than the lower part of a barometer, viz. a tube of about 8 or 9 inches in length, filled with mercury, and immerſed with its aperture into a ſmall quantity of mercury contained in a glaſs veſſel, which forms the ciſtern. This gage is either placed under the receiver upon the principal plate of the pump, or it is placed under a ſeparate ſmall receiver, upon a little auxiliary plate, which ſome air-pumps have expreſsly for that purpoſe, as in fig. 17. Plate XVI. It is evident that this gage, not being equal to a whole barometer, will not ſhew the very ſmall degree of rarefaction; but we are ſeldom intereſted concerning thoſe ſmall degrees, and in general this gage will begin to ſhew the rarefaction when about three quarters of the air have been removed from the receiver, viz. when the air has been rarefied till its remaining elaſticity is not able to ſupport that column of mercury. This gage has a ſcale of inches and parts of an inch affixed to the tube, which ſhews the preciſe altitude of the mercury in it.

The long barometer gage is a tube of about 33 inches in length, open at both ends, having its lower end immerſed in a ciſtern of quickſilver, which is fixed on the pedeſtal, or lower part of the frame of the pump (for the tube itſelf reaches from that place to the height of the plate). The upper aperture of the tube communicates, by means of a braſs tube, with the inſide of the pump.

This in fact is an empty barometer, which is filled with quickſilver by withdrawing the air from it through its upper aperture; and if the pump could produce a perfect vacuum, the mercury in this long gage would riſe as high as it does in a common barometer; but as the pump cannot exhauſt ſo far, therefore the difference of altitude between the mercury of the long gage, and that of a common barometer, ſhews the quantity of air that remains in the receiver. This difference of altitude is ſhewn by a ſcale of inches and parts of inches,

inches, which is always affixed to the long barometer gage. As the altitude of the mercury in a common barometer, is to the contemporaneous altitude of the mercury in the long barometer gage, ſo is the whole quantity of air which was in the receiver before the rarefaction, to that quantity which has been drawn out of it.

The ſyphon gage is nothing more than the ſhort barometer gage, except that inſtead of terminating in a little ciſtern, in this gage the tube is bent and riſes upwards with its aperture, which by means of a braſs tube is made to communicate with the inſide of the pump; ſo that the aſcending leg of the tube performs the office of a ciſtern; hence, in rarefying the air, the mercury deſcends from the cloſed end of the tube, and riſes into the aſcending leg; therefore the altitude of it in one leg above its altitude in the other leg (which leg in fact is the ciſtern) ſhews the degree of rarefaction, and this altitude is denoted by an annexed ſcale of inches and parts of inches. Such a gage is partly ſeen at *g*, fig. 2. Plate XVI.

The above-mentioned gages evidently indicate the elaſticity of the fluid, which remains in the receiver of the pump after a certain degree of rarefaction; and it is immaterial whether that elaſtic fluid be air, or vapour of water, or other elaſtic fluid; but there is another gage, which from its ſhape was called, the *pear-gage*, by its inventor, Mr. Smeaton, and which ſhews (not at the actual time, but after the readmiſſion

miſſion of air into the receiver) how much air was left in the receiver in the preceding rarefaction.

The pear-gage conſiſts of a glaſs veſſel A, fig. 6. Plate XVI. which has a ſmall projecting orifice B, and at the other end is extended into a tube cloſed at D; the capacity of this tube is the hundredth part of the capacity of the whole veſſel. This gage is ſuſpended, with its aperture downwards, to the lower end of a ſlip-wire (viz. a wire which paſſes through a collar of leathers) within a glaſs receiver of the pump, and exactly under it, a little cup, containing quickſilver, is placed upon the plate of the pump. When the pump has been worked to the intended degree, the air in the pear-gage is evidently rarefied as much as it is in the receiver. In that ſtate, by lowering the ſlip-wire, the pear-gage is let down till its aperture B has reached the bottom of the mercury. This done, the external air is admitted into the receiver; but it cannot be admitted into the pear-gage, becauſe the aperture B of that gage is now immerſed in the quickſilver; but the preſſure of the atmoſphere on the ſurface of the quickſilver, forces that fluid metal into the pear-gage, and fills it up to a certain degree E; then the upper part D E of the gage will contain all the air or vapour which occupied the whole cavity of the gage during the rarefaction. There is a divided ſcale annexed to the upper part D E of the gage, which ſhews what part of the capacity of the whole gage is filled with air, and of courſe it manifeſts the

the degree to which the rarefaction of the air had been carried. For inſtance, if we find that the part D E of the gage, which is filled with air above the quickſilver, is the 500th part of the whole, we may conclude, that the air in the receiver had been rarefied 500 times, &c.

But a very conſiderable difference muſt be remarked between the indications of this, and of the preceding gages.

When the receiver contains no other fluid beſides air, then the pear-gage and the other gages indicate the ſame degree of rarefaction; but if the receiver contain the vapour of water, or of other liquor, then the pear-gage will indicate a much greater degree of rarefaction than the other gages; becauſe the vapour which has elaſticity ſufficient to ſupply the place of air in the receiver, on the readmiſſion of air, is condenſed into a ſpace vaſtly ſmaller than the ſame quantity of rarefied air can be condenſed into; ſo that the pear-gage ſhews the quantity of *air* alone which had been left in the receiver; whereas the other gages ſhew the quantity of elaſtic fluid which is actually remaining in the receiver.

Fig. 16. Plate XVI. repreſents a veſſel proper for weighing air. It is a glaſs veſſel in the ſhape of a Florence flaſk, having a ſocket of braſs with a ſtop-cock cemented on its neck. The aperture A of the braſs part is formed into a ſcrew, which fits the ſcrew in the middle of the plate of the pump.

This veſſel, being ſcrewed on the pump, and the ſtop-cock B being opened, is exhauſted; then the ſtop-cock is turned ſo as to ſhut up the aperture, the veſſel is unſcrewed from the pump, and is weighed in an accurate pair of ſcales. This done, the ſtop-cock B is opened, and the air is admitted into the veſſel, which is then weighed again, in which ſtate it will be found to weigh more than it did in its exhauſted ſtate. The difference of the two weights is the weight of a quantity of air, of the actual denſity of the atmoſphere, equal in bulk to the capacity of the veſſel. Yet, ſince no air-pump produces a perfect vacuum, the above-mentioned veſſel, in what we have called its exhauſted ſtate, does actually contain a ſmall quantity of air, which renders the reſult inaccurate. But this inaccuracy may be corrected in a very eaſy manner, by obſerving the preciſe degree of rarefaction, as indicated by the gage, and allowing for the remaining quantity of air. Thus, for inſtance, ſuppoſe that the gage indicates that the air has been rarefied 80 times; therefore the air which remains in the veſſel, is the 80th part of its whole capacity. In this ſtate let the veſſel weigh 9000 grains, and when full of air, let it weigh 9160 grains, the difference of which weights is 160 grains, and this is the weight of a quantity of air equal to $\frac{79}{80}$ths of the capacity of the glaſs; therefore the 160 grains muſt be increaſed by the 80th part of that number, viz. of 2 grains, then the ſum, which is 162 grains, is the weight of a quantity of air equal to the whole capacity of the veſſel.

If inſtead of weighing common air, in the above-mentioned veſſel, it be required to weigh ſome other ſort of permanently elaſtic fluid, the operation muſt proceed as above, excepting that before the ſtop-cock B be opened, previouſly to the ſecond weighing, the end A muſt be ſcrewed or faſtened to the neck of a bladder, or other receiver, full of that other ſort of elaſtic fluid; ſo that the veſſel may be filled with it, inſtead of common air. It is then weighed again, &c.

The Condenſing Engine.

The principle of the condenſing engine will be eaſily comprehended; for if in the exhauſting engine, fig. 18. Plate XVI. the valves be reverſed, viz. the valves at B, and at G in the piſton, be turned upſide down, that engine will become a condenſing engine; ſince in that caſe, when the piſton is drawn towards A, the air will ruſh through the valve at E, into the barrel; and when afterwards the piſton is puſhed downwards, the air of the barrel will be puſhed through the valve at B, and will be condenſed into the veſſel D. Yet an exhauſting ſyringe is made in a manner ſtill more ſimple; ſee fig. 15. of Plate XVI. The cylinder has one valve at its lower aperture B, which opens outwards;

outwards; the piſton is not perforated, but ſolid; and there is a hole on the ſide of the barrel, at C. When the piſton is drawn upwards, a vacuum is formed in the lower part of the barrel; but as ſoon as the lower part of the piſton is raiſed above the hole C, the air ruſhes through that hole, and fills the barrel; then, on lowering the piſton, the air is condenſed into the lower part of the barrel, and is forced out at B, into any veſſel, to which that end of the ſyringe is ſcrewed. With this ſyringe the air is condenſed into the inſide of a water fountain, or of a wind-gun, which inſtruments are ſo commonly deſcribed in philoſophical works, &c. that they need not be inſerted in this place. But for the purpoſe of performing a variety of philoſophical experiments in condenſed air, ſuch a ſyringe is adapted to a frame and apparatus, as at fig. 1. Plate XVII. and this apparatus is commonly denominated a *condenſing engine.*

CD is a braſs condenſing ſyringe, which, when by applying the hand at Z, the piſton is moved alternately up and down, forces the air through the braſs pipe DNF, into the glaſs receiver AB. This receiver muſt be very thick, and well annealed: it is ſet with its ſmooth and flat edge on the plate of the machine, which is ſimilar to the plate of an air-pump; a thick piece, LM, of braſs, is applied in a ſimilar manner to the upper aperture of the glaſs receiver, and a ſlip-wire paſſes through a collar of leathers in this braſs piece. As the force of the condenſed

condenſed air would lift up the braſs piece, L M, from over the receiver, or lift up the latter from the plate, ſo the receiver and braſs piece are kept down by the croſs piece of wood G H, which is adjuſted by means of the ſcrew-nuts on the ſteady pillars I, K.

There is a gage, E F, annexed to this machine, which indicates the condenſation of the air within the receiver and tube of communication. It conſiſts of a ſtrong and narrow glaſs tube hermetically cloſed at E, and connected with the braſs pipe of communication at F. A ſmall quantity of quickſilver fills up a ſhort part of the cavity about the middle of the tube, and the ſpace between the mercury and the cloſed end E of the tube, contains air of the uſual denſity. Now when the air is condenſed in the receiver, in the tube of communication, &c. the mercury is thereby impelled farther towards E, and the contraction of that ſpace, which is ſhewn by an annexed ſcale, ſhews the degree of condenſation; for inſtance, if the air which is contained in that ſpace is, by the condenſation, forced into half the ſpace it occupied before, the concluſion is, that the air within the receiver is as denſe again as it was previous to the condenſation; and this is generally expreſſed by ſaying, that then the receiver does contain two atmoſpheres; if the air at E be contracted into a quarter of its original ſpace, then four atmoſpheres have been forced into the receiver; and ſo on *.

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* The condenſation is inverſely as the ſpace occupied by the air at the extremity E of the gage.

Certain

Certain air-pumps, as that of Mr. Smeaton, and the firſt which was contrived by Mr. Haas, can be made to exhauſt or to condenſe at pleaſure, which is done by changing the communication between the cylinders and the plate of the pump; for as in thoſe pumps the air is rarefied towards one end, and is condenſed towards the other end of each barrel, the machine will exhauſt if the former end of the barrel be made to communicate with the plate of the pump, and the latter with the atmoſphere; but it will become a condenſer, if the latter end of the barrel be made to communicate with the hole in the centre of the plate, and the former with the atmoſphere.

CHAPTER XV.

CONTAINING THE PRINCIPLES OF CHEMISTRY, AND PARTICULARLY THE DESCRIPTION OF THE PRINCIPAL OPERATIONS AND APPARATUS.

CHEMISTRY is the ſcience which endeavours to aſcertain the number, the quantities, and the properties, of the conſtituent principles of all natural bodies. It alſo endeavours to form new or artificial compounds.

The ſeparation of the component principles of a body from one another, is called *analyſis*. The formation of compound bodies from ſimpler ſubſtances, is called *ſyntheſis*.

Both the analyſis and the ſyntheſis are performed by means of certain operations, which are therefore called *chemical operations*, or *chemical proceſſes*.

It has been ſaid above, page 19. that there is a mutual attraction between the parts of the ſame ſubſtance, which is called attraction of aggregation; and that there is, likewiſe, a mutual attraction between the heterogeneous parts of different bodies, which, when it is merely ſuperficial, is called *attraction of coheſion*; but it is called *attraction of affinity, or of compoſition*, when it produces an intermixture of two or more heterogeneous ſubſtances, and a change of ſome, at leaſt, of their properties.

Now it muſt be remarked, that the affinity of one ſubſtance to another, differs in degree according to the different ſubſtances; and it is upon the difference of thoſe affinities that the operations of chemiſtry are eſtabliſhed; for if the affinity between two bodies were equal to the affinity between any two other bodies, chemiſtry could not exiſt. Thus for inſtance, it is known that A and B have a certain degree of attraction or affinity towards each other; alſo, that there is a greater affinity between A and C; and a much greater affinity between C and D. Now, if I wiſh to analize a certain body, which is a compound of A and B, I mix that body with the body C, in conſequence of which, as C has a greater affinity to A than to B, the given body will be decompoſed; and one of its ingredients, viz. A, will form a new compound with C, whilſt the other ingredient B will be left by itſelf. Then I mix the new compound of A and C, with D, in conſequence of which this new compound will be decompoſed, C will adhere to D, and A will be left by itſelf. Thus I obtain A and B, viz. the two components of the given body, in a ſeparate ſtate.

The attraction of aggregation counteracts, or is oppoſite

oppoſite to the attraction of affinity; for the weaker one of them becomes, the greater power will be gained by the other.

The attraction of affinity acts more powerfully in proportion as the quantity of contact between the different bodies is increaſed; hence the action between two bodies that have a certain affinity, is weak or imperceptible when both the bodies are in a hard ſolid ſtate; it becomes ſtronger when the bodies are ſoftened by means of heat, (which diminiſhes the attraction of aggregation) or when they are pulverized and intermixed:—ſtronger ſtill, when one of the bodies is in a fluid ſtate; and it will become as active as poſſible, when both the bodies are in a fluid ſtate. Therefore, in order to decompoſe, or to compoſe, different bodies, it is neceſſary to pulverize, or to heat, or to mix, or, in ſhort, to perform diverſe operations with a variety of neceſſary inſtruments, according as may be required by the nature and properties of the different articles. Hence the whole ſubject of chemiſtry conſiſts, 1ſt, of the art of performing the neceſſary operations; and 2dly, of the knowledge of the principal facts, which have been aſcertained by means of thoſe operations. The ſecond of thoſe objects is what immediately belongs to the preſent part of theſe elements of natural philoſophy, which treats of the peculiar properties of bodies; we ſhall nevertheleſs premiſe a competent account of the principal operations, through which moſt of the peculiar properties

perties of bodies have been aſcertained, and by the means of which new diſcoveries may be made.

Trituration, *pulverization*, and *levigation*, (viz. the reduction of ſolids into powders of different fineneſs) are performed by means of the hammer, raſps, files, graters, mortars and peſtles, or a flat ſtone and muller. Moſt of thoſe tools, viz. the hammer, mortars, peſtles, ſtones and muller, are either of wood, or metal, or glaſs, or porcelain, or marble, or agate, &c. according to the hardneſs and other properties of the articles that are to be pulverized. But theſe muſt be conſidered amongſt the preliminary operations; for they only alter the bulk, and not the nature of the articles; ſince every particle of a pulverized body is a ſmall whole of that body; whereas the real chemical operations deſtroy the aggregation of bodies, ſeparate their conſtituent principles, form new compounds, and alter ſome of, if not all, their properties.

The ſeparation of the finer parts of bodies from the coarſer, which may want farther pulverization, is performed by means of *ſifting*, or *waſhing*.

A *ſieve*, for ſifting, generally conſiſts of a cylindrical band of thin wood, or metal, having acroſs its middle a perforated diaphragm of ſilk, or leather, or hair, or wire.

Sieves are of different ſizes and different fineneſs. Fig. 3. of Plate XVII. ſhews a ſieve of the beſt conſtruction. It conſiſts of three parts, A, B, C. The middle part B is properly the ſieve; D is the perforated diaphragm, through which the powder paſſes; C is a bottom which may be put on, or taken off, the lower part of B, and ſerves to receive the powder that paſſes through the ſieve; A is a top or lid, which is placed on the upper part of B, and ſerves to prevent the falling off, or the diſſipation into the air, of the materials. When all the three parts are together, the ſhape of the ſieve is as in fig. 7. Plate XVII.

By waſhing, one may ſeparate powders of an uniform fineneſs much more accurately than by means of the ſieve; but it can only be uſed for ſuch ſubſtances as are not acted upon by the fluid which is uſed. The powdered ſubſtance is mixed with, and is agitated in, water, or other convenient fluid; the liquor is allowed to ſettle for a few moments, and is then decanted off; the coarſeſt powder remains at the bottom of the veſſel, and the finer paſſes over with the liquor. By repeated decantations in this manner, various ſediments are obtained of different degrees of fineneſs; the laſt, or that which remains longeſt ſuſpended in the liquor, being the fineſt.

Filtration is a finer ſpecies of ſifting. It is ſifting through the pores of paper, or flannel, or fine linen, or ſand, or pounded glaſs, or porous ſtones, and the like; but it is uſed only for ſeparating fluids from ſolid or groſſiſh particles, that may happen to be ſuſpended in them, and not chemically combined with the fluids. Thus ſalt water cannot be deprived of its ſalt by filtration; but muddy

water

water may. No ſolid, even in the form of powder, will paſs through the above-mentioned filtering ſubſtances; hence, if water or other fluid, containing ſand, inſects, mud, &c. be placed in a bag, or hollow veſſel, made of any of thoſe ſubſtances, the ſand, &c. will remain upon the filter, and the liquor will paſs clear through the filter, and may be received in a veſſel placed under it*.

Lixiviation is the ſeparation by means of water, or other fluid, of ſuch ſubſtances as are ſoluble in that fluid, from other ſubſtances which are not ſoluble in it. Thus, if a certain mineral conſiſt of ſalt and ſand, or ſalt and clay, &c. the given

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* Filtering paper is paper without ſize. For this purpoſe the piece of paper is ſhaped into the form of a cone, and is placed into a funnel, in order to ſupport it, otherwiſe, when wet, it would eaſily break.

Filtering ſtones and filtering baſons, either natural or artificial, for the purpoſe of purifying water, are not unfrequently uſed in this and other countries. Rocky mountains, beds of ſand, gravel, &c. are natural filters.

The compoſition for making filtering baſons for purifying water, conſiſts of equal parts of tobacco-pipe clay, and coarſe ſea, river, drift, or pit ſand. The baſons are formed and turned on a potter's wheel. They ſhould be about $\frac{3}{4}$ of an inch thick. When the veſſels are of the uſual degree of dryneſs, the whole outſide and inſide ſurface muſt be ſhaved or turned off on a potter's wheel; and, when perfectly dry, thoſe baſons are burnt or baked in a potter's kiln after the uſual manner.

body being broken into powder, is placed in water, which will diſſolve the ſalt, and keep it ſuſpended, whilſt the earthy matter falls to the bottom of the veſſel, and, by means of decantation, may be ſeparated from the fluid. If the ſalt, or other ſubſtance, which is diſſolved in the fluid, be required to be ſeparated from it, then recourſe muſt be had to

Evaporation, which ſeparates a fluid from a ſolid, or a more volatile fluid from another which is leſs volatile.

Simple Evaporation, properly ſpeaking, is uſed when the more volatile or fluid ſubſtance is not to be preſerved; and, in that caſe, the evaporation is performed in veſſels of wood or glaſs, or porcelain or metal, &c. which are either ſimply expoſed to the air, or are placed upon a fire, more or leſs active, according to the nature of the ſubſtances.

When the fluid, which is evaporated, muſt be preſerved, then the operation is called *diſtillation*, and is to be performed in other veſſels, which are called *retorts*, *alembics*, *ſtills*, &c. made either of glaſs, or porcelain, or metal, &c.

The office of thoſe veſſels is to condenſe the vapour into a liquid form, and to convey it into a recipient. The evaporation is performed by means of heat;—the condenſation by means of cold; therefore the body of any of thoſe veſſels, which receives the materials, muſt be placed upon a fire, or hot

place;

place; but that part of the veſſel which condenſes the vapour, and is hence called the *refrigeratory*, muſt be rendered ſufficiently cool for the purpoſe.

Fig. 2. Plate XVII. repreſents a retort. In this diſtilling inſtrument, the materials are placed in the body E A F, and the bottom A is placed upon the fire*. The vapours which riſe from the materials at E F, paſs through the tube E B C, which being at ſome diſtance from the fire, and therefore cooler, condenſes the vapour into liquid drops, which, on account of the inclination of the tube B C, run down into the recipient D, which is adapted to the neck of the retort †. Thus the ſolid part of the materials in E A F remains in the retort, and the fluid part paſſes over into the receiver.

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* In order to prevent its breaking, the bottom of the retort is generally covered with ſome adheſive ſubſtance, which can ſtand the fire, ſuch as clay, a mixture of lime and clay, &c. this is called *luting* the retort; or the retort is placed in a baſon of ſand or water, and this baſon is then placed immediately upon the fire.

† The receiver muſt not, in moſt caſes, be cloſed very accurately upon the neck of the retort; for that may occaſion the burſting of the inſtrument; but when that accurate cloſing is practicable, it may be accompliſhed by the application of wet paper, or wet rags, or a mixture of wax and turpentine, or a mixture of whitening and oil, &c.

This inſtrument is uſed when the quantity of materials is ſmall; and the vapours may eaſily be condenſed; otherwiſe an alembic, ſuch as fig. 4. Plate XVII. is uſed. This inſtrument conſiſts of two parts. A B is the body which receives the materials. AC is the capital, which is joined cloſe to the body. The upper part of the capital is formed into a baſon C, in which cold water is placed, which condenſes the vapour in the cavity *i*, ſo that the drops of liquor fall in the grove *o*, *o*, and come out of the tube D into the recipient. In diſtilleries and other large works, the capital has not the baſon or refrigeratory C; but the tube D is made very long, and is ſhaped into a ſcrew-like form, called *a worm*, which is placed into a tub of water, and has its aperture out on one ſide of the tub. Then that worm and tub forms the refrigeratory.

When the materials which are evaporated in the body of the diſtilling veſſels, concrete not in a fluid but in a ſolid form, within the neck of the retort or tube, &c. then that diſtillation is more properly called *ſublimation*.

By the above means one fluid may be ſeparated from other materials; but it often happens that in diſtillation ſeveral fluids are produced, ſome of which are permanently elaſtic, and all or moſt of them may be required to be preſerved. In this caſe, another ſort of apparatus muſt be uſed, which is called

The Apparatus for Pneumato-chemical Diſtillations. See fig. 5. Plate XVII. A is a tubulated retort*, adapted to the recipient B, which has two necks. To the upper neck of this recipient is fitted a bent tube C D E, whoſe other extremity reaches as far as very near the bottom of the recipient G. This recipient has three necks *a*, *b*, *c*, into the firſt of which the end of the tube D E is fitted; into the ſecond, *b*, an open tube, which reaches very near the bottom of G, is fitted; and to the laſt neck, *c*, a crooked tube is adapted, which opens and diſcharges the elaſtic fluid into a proper receiver. Sometimes two or three, or more, veſſels, like G, are interpoſed; viz. inſtead of the crooked tube F, a tube, like C D E, is adapted to the veſſel G, and to the next which is ſimilar to it, and ſo on; then the crooked tube F is applied to the laſt neck of the laſt of thoſe veſſels.

When this apparatus is properly connected, the materials are put into the retort through the hole O, and a proper degree of heat is applied to the bottom of the retort; then the products will be collected in different parts, viz. what is ſublimed, or concreted, in a compact form, adheres to the neck of the retort; the fluid of eaſieſt condenſation is collected into the receiver B; the elaſtic vapours,

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* When the retort has a hole and ſtopple, as at O, which is uſeful for introducing or ſtirring the materials; it is then called *a tubulated retort.*

which are condenſable in water, will be combined with the diſtilled water, which muſt be placed at the bottom of the veſſel G, and thoſe which are not ſuſceptible of being thus abſorbed, paſs through the tube F into a proper receiver, or they may be made to paſs through other ſucceſſive veſſels ſimilar to G, in which ſuch other fluid may be placed, as may be capable of abſorbing one or more of the permanently elaſtic fluids. The tube H ſerves to admit ſome atmoſpheric air, in caſe the water in G ſhould abſorb the produced elaſtic fluid too quickly.

In certain caſes of mixtures, the produce is merely an elaſtic fluid, which is required to be collected. For this purpoſe, the veſſel repreſented in fig. 6. Plate XVII. is very uſeful. It conſiſts of a body A, to which a perforated ſtopple, with the crooked tube C, is adapted. The materials are placed in A, and the elaſtic fluid which is generated, paſſes through B C D, into a proper receiver.

Such receiver, and the reſt of the apparatus proper for receiving, meaſuring, mixing, and performing other operations on permanently elaſtic fluids, is delineated in fig. 8. Plate XVII. A B C D E is a wooden trough, having a ſhelf F, G, and filled with water as high as about an inch or two above the ſhelf. There are ſeveral glaſs jars, or receivers, as H, I, K, L, which ſerve for retaining, mixing, meaſuring, and otherwiſe

uſing

uſing the permanently elaſtic fluids. Thoſe jars are firſt filled with water in the trough, then they are turned upſide down, and being lifted up gently, ſo as not to elevate their aperture above the water, they are placed upon the ſhelf, as repreſented at G. Then if a veſſel full of air be placed with its aperture downwards into the water of the trough, and there it be turned upſide down, juſt under one of the jars full of water, the air or permanently elaſtic fluid being the lighter fluid of the two, will aſcend into the latter veſſel, and all or part of the water will come out of it, according to the quantity of air introduced.

For the purpoſe of rendering this operation more commodious, ſome holes are ſeen in the ſhelf, which are the apertures or apexes of as many inverted funnels, or little domes dug out of the thickneſs of the ſhelf; ſo that when a veſſel full of air is inverted under one of thoſe holes, whereupon a jar full of water is placed as at G, the air will come out of the former veſſel, and paſſing through the hole in the ſhelf, will enter the latter veſſel.

At F there is repreſented a jar which receives the air that is generated from the materials in the phial M, ſimilar to the phial, fig. 6. There the phial is repreſented as heated by the flame of a candle, which in ſeveral experiments muſt be done, in order to aſſiſt the extrication of the elaſtic fluid. This fluid is conveyed through the crooked tube, and is diſcharged under one of the holes of the ſhelf through which it paſſes into the receiver I, and in proportion as the elaſtic fluid aſcends under the form of bubbles, the water ſubſides.

A ſmall glaſs veſſel L, capable of containing about an ounce meaſure, is uſed as a meaſure of a permanently elaſtic fluid; for if this phial be ſucceſſively filled and inverted under a large jar, we may thereby throw into that jar any required quantity of an elaſtic fluid, or as many meaſures of one elaſtic fluid, and as many of another, as we pleaſe.

When a glaſs jar is partly filled with an elaſtic fluid, we may meaſure the quantity of that fluid by meaſuring the diameter and altitude, or the capacity of that part of the veſſel, in the uſual geometrical way of gauging veſſels. But for the ſake of greater expedition and accuracy, the contents of a veſſel are ſometimes marked on the outſide of it. Thus the tube, or narrow veſſel, K, is marked on the outſide, ſhewing the ſpace which is occupied by each ſucceſſive meaſure of air, ſuch as is contained in the meaſuring phial L. Such a veſſel as K is moſtly employed for examining the purity of common or reſpirable air. This is done by mixing a certain quantity, as a meaſure or two, of reſpirable air, with a certain quantity of another permanently elaſtic fluid, or of ſome other ſubſtance capable of occaſioning a diminution of the bulk of the elaſtic fluid, and then meaſuring the diminution; for the purity of the reſpirable fluid is proportionate

proportionate to that diminution. The parts of a meaſure are ſometimes marked upon the tube K itſelf, and at other times are aſcertained by the external and occaſional application of a divided ſcale. The tube K, or in general any ſuch veſſel as is uſed for aſcertaining the purity of reſpirable air, is called an *Eudiometer*.

It is ſometimes required to remove an inverted jar with its contents from the ſhelf of the trough: this is done by the uſe of a ſhallow pan or diſh, which is immerged in the water of the trough, and the jar is ſlipped in it; then the whole may be removed and placed wherever it may be convenient, as at P. In this caſe the ſhallow pan performs the office of a ſmall trough; and for ſuch purpoſes ſeveral diſhes or pans of different ſizes ſhould be had in readineſs.

Some elaſtic fluids are inflammable, and in order to try their inflammability a ſmall phial may be filled with any of them, and after having ſtopped its aperture with a finger, it may be removed from the water; then being brought with its aperture near the flame of a candle, the finger is removed, and the elaſtic fluid will take fire, as may be clearly ſeen in the dark, and even in the day light. When the quantity is not very ſmall, a pretty large jar is filled with it, and the palm of the hand is applied to the aperture; in that ſituation the jar is removed from the water, and is turned with the aperture upwards. Then having in readineſs a twiſted wire with

with a bit of lighted wax taper at its extremity, the hand is removed, and the lighted taper is dipped in the veſſel, &c. as ſhewn at Q.

Some of the permanently elaſtic fluids are abſorbed by water; therefore they cannot be confined by water. For ſuch fluids, it becomes neceſſary to uſe a trough full of quickſilver; but on account of the price and weight of the mercury, a much ſmaller trough and ſmaller glaſs veſſels muſt be uſed.

The ſolution of ſalts in water, the diſſolution of metallic and other ſubſtances in different menſtrua, require a variety of veſſels, whoſe form, viz. whether open or cloſe, or deep, &c. is eaſily ſuggeſted by the nature of the articles.

When a ſalt is diſſolved in water or other fluid, and by evaporation the fluid is driven off, the ſalt gradually acquires the ſolid form, and in doing this it arranges its particles in a particular manner; as, for inſtance, ſome ſalts arrange themſelves under the form of cubes, other under the form of globules, &c. The ſame thing happens with ſome earthy particles, and ſeveral other ſubſtances. Now this ſpontaneous regular arrangement is called *cryſtalization* *.

Veſſels, generally open, but ſometimes cloſed, are employed for ſuch cryſtalizations; and the cryſ-

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* See the Abbe Hauy's Work on the Structure of Cryſtals.

talization of ſome ſubſtances requires a certain temperature, that of others requires an higher, or a lower temperature; hence the charged veſſels muſt be placed in cool places, &c.

The fuſion of metallic ſubſtances by means of heat, requires veſſels ſufficiently ſtrong to reſiſt the fire. Thoſe veſſels are moſtly, if not always, made of earthenware or porcelain, or a mixture of clay and powder of black-lead. They are called *crucibles*, and their more uſual ſhapes are repreſented at fig. 9. Plate XVII.

Some of thoſe crucibles have covers likewiſe of earthenware; but ſometimes the fuſed metal muſt be expoſed to a current of air. In that caſe the proper crucibles are ſhallow and broad, as at fig. 10. Plate XVII. Theſe are called *cuppels*, and they are formed either of calcined bones, mixed with a ſmall quantity of clay, or of a mixture of clay and black-lead powder. But the cuppels muſt not be placed in a cloſe furnace, or be ſurrounded by coals; for in that caſe the required current of air could not have acceſs to the fuſed metal. They are therefore placed under a ſort of oven of earthenware, which is called a *muffle*, as repreſented at fig. 13. Plate XVII. and the muffle, containing the cupples, &c. is expoſed to the fire of the proper furnace.

The various degrees of heat, which are required for the performance of chemical operations, viz. from the heat of a ſmall wax taper, to that of the moſt

moſt powerful furnace, render a variety of fire-places or furnaces neceſſary for a chemiſt. Thoſe furnaces are either open at top, or they are covered with what is called a *dome*, and have a chimney, or tube, to carry off the heated air, ſmoke, &c. They are ſometimes ſupplied with air from the natural action of the fire, which rarefies the air about the ignited fuel, and the rarefied air becoming ſpecifically lighter, aſcends into the chimney, and other colder, and conſequently heavier, air, is forced by the atmoſphere to enter at the lower part of the furnace. Some furnaces are ſupplied with air by means of bellows; and thoſe are applied for forging iron, or for reducing metals from the ore, which is called *ſmelting*, &c. Hence the furnaces derive their various names, and are called ſimple, or open, furnaces; reverberatory furnaces; wind, or air, furnaces; blaſt, or bellows, furnaces; forges; ſmelting furnaces, &c.*

When a pan full of ſand, or of water, is placed over a common furnace, and a retort, or other veſſel, is placed in the ſand, or water; that mode of applying heat is called a *ſand bath*, or *water bath*.

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* The particular deſcription of the various furnaces may be ſeen in a variety of chemical works: Macquiar's Dictionary of Chemiſtry, and Lavoiſier's Elem. of Chem. are ſome of the beſt for this purpoſe.

There are ſeveral other chemical operations, expreſſions, and tools, which are ſo obvious, common, or ſimple, as to need little or no particular explanation. The following are the moſt remarkable.

The *dry way* of performing chemical operations, is when ſtrong degrees of heat are uſed, and the *humid way* is when fluid ſolvents, and at moſt low degrees of heat, are uſed.

Combuſtion is when a body is burned with the aſſiſtance of reſpirable air. *Deflagration* is when the combuſtion is attended with little exploſions or cracklings. *Detonation* is a pretty loud report.

The word *mixture* is commonly underſtood; but the mixing of bodies, which have a great affinity to each other, requires a variety of precautions; for ſometimes ſuch mixtures are attended with heat, ebullition, exploſions, and ſuch like dangerous effect. They muſt, according to the nature of the materials, be made either ſlowly, or ſuddenly, in open veſſels, or cloſed phials; they muſt ſometimes be aſſiſted by agitation, ſtirring, heating; and at other times muſt be left undiſturbed; but the time and the mode of adopting any one or more of thoſe particular applications, muſt be learned from practice, and from a competent knowledge of the nature of the ingredients.

When a ſolid ſubſtance in powder, or otherwiſe, is left for a certain time in a fluid, and the mixture is kept

kept expoſed to a ſlow degree of heat; that proceſs is called *digeſtion.*

When a ſubſtance, which has an affinity to another ſubſtance, is mixed with as much of that other ſubſtance, as its affinity will enable it to hold in combination, then the former ſubſtance is ſaid to be *ſaturated,* or the mixture to have attained the point of *ſaturation.* If the mixture contain a greater proportion of either ſubſtance, then that mixture is ſaid *to contain an exceſs of,* or *to be ſurcharged with that other ſubſtance.* The ſame thing muſt be underſtood of the compounds of more than two ſubſtances.

CHAPTER XVI.

CONTAINING A SKETCH OF THE MODERN THEORY OF CHEMISTRY.

THE grand principle of all chemical proceſſes, which enables us to decompoſe certain bodies, and to compound others, is that *every ſubſtance has a certain peculiar affinity for other ſubſtances, but not in equal degree.*

This principle, though long known, could not, however, be univerſally applied to explain all the variety of chemical phenomena, on account of the undiſcovered nature of ſeveral powerful agents in nature, and on account of the ſuppoſed action of others which have no real exiſtence.

The wrong or confuſed knowledge relative to heat, fire, air, light, &c. rendered a variety of facts abſolutely inexplicable; certain effects appeared to be contradictory; ſome ſeemed to have nothing to do with the principle of affinities, and others were explained upon the ſuppoſed exiſtance of an inflammable principle called *phlogiſton.*

The modern philoſophers (I mean ſince the year 1780, or thereabout), aſſiſted by the diſcoveries, the knowledge, and even the errors, of their predeceſſors, having inveſtigated, with infinite labour and ingenuity, the nature of thoſe powerful natural agents, have found reaſon to explode the ſuppoſed exiſtence of the phlogiſton, and have been able to form a theory, which is incomparably more general, leſs complicated, and more ſatisfactory, than any other preceding theory.

This theory conſiders every proceſs, which produces a change of ſome or of all the properties of the bodies in action, as depending on the various elective attractions of thoſe bodies, or of their components; and, in general, the reſult of every ſuch proceſs is the decompoſition of certain compound bodies, and the formation of others.

Not only the mixtures of metallic ſubſtances with acids or alkalies; the formation of ſoaps, the formation of compound ſalts, the purification of metals, and ſuch other operations as are performed in chemical laboratories; but whatever compoſition or decompoſition, with change of properties, takes place in nature, ſuch as the burning of combuſtible bodies, the ruſting of iron, the evaporation of water, animal reſpiration, the growth of animal and vegetable bodies, their fermentations and putrefactions, &c. have, in great meaſure, been proved to depend, (and, by analogy, we are led to believe that they do all depend) upon the elective attractions of the various ingredients.

A few examples will be neceſſary to illuſtrate this doctrine: but thoſe will be found in the next Chapter; for in this we muſt ſtate ſome general obſervations on the nature of the primitive or elementary ſubſtances, which are the agents in all natural and chemical proceſſes. A liſt of thoſe ſubſtances has been inſerted in the firſt volume of this work, as alſo in the preſent volume, pages 15 and 16, to which the reader is referred.

The *light* which is perceived by our eyes, is ſuppoſed to be the effect of a peculiar fluid, which proceeds from the ſun, a candle, a fire, or other luminous object. We cannot confine it in veſſels, nor can we weigh it, nor meaſure its quantity, excepting in ſome degree by compariſon, viz. of two luminous bodies, we may determine which is the moſt luminous. But light ſeems to enter into combination with certain bodies, and by that combination to produce particular effects; for inſtance, plants that are kept growing in the dark, loſe their green colour, and become white or pale. Plants which grow in confined places, always endeavour to turn their tops and tender branches towards the light;—their flavour, their vigour, their fragrance, are much greater when they have been expoſed to much light in the courſe of their vegetation, than otherwiſe.—There are likewiſe ſeveral other effects produced by light in various chemical proceſſes.

Caloric is ſuppoſed to be a peculiar fluid, which produces in us the ſenſation of heat. We can neither weigh it, nor confine it in veſſels. A greater or leſs quantity of it is contained in bodies of every ſort. It paſſes through all ſorts of bodies, but eaſier through ſome, ſuch as the metals, than through others, ſuch as charcoal, wood, &c. hence certain bodies are ſaid to be better or worſe *conductors* of heat than other bodies.

Caloric enters into combination with various ſubſtances; viz. it poſſeſſes peculiar affinities; and very ingenious methods have been diſcovered for aſcertaining the comparative quantities of it, which are abſorbed, retained, or diſengaged in a great variety of proceſſes. As a mixture of two ſubſtances muſt naturally have a greater bulk, than either of them ſingly; ſo by the acceſſion of caloric a body is enlarged in its dimenſions, and, of courſe, from their being placed farther from each other, the attraction of aggregation between the conſtituent particles of that body is weakened: hence every body is expanded by heat, and is rendered more or leſs conſiſtent by the acceſſion of various degrees of caloric. Amongſt thoſe various degrees of conſiſtency, we diſtinguiſh three principal ſtates, viz. the ſolid, the liquid, and the aëriform ſtate. Thus water, according as more and more caloric is communicated to it, aſſumes, firſt the ſolid ſtate of ice, next that of fluid water, and then the aëriform ſtate, or what is called *vapour* *. If preſſure,

or

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* It is not unlikely that by a further expanſion, and perhaps by the combination with the electric, or other fluid,

the

or the contact of other bodies, which have a greater affinity for caloric, come into contact with a ſubſtance in a ſtate of vapour, that ſubſtance becomes a liquid, and then a ſolid, harder and harder.

Certain bodies, when they have acquired a quantity of caloric ſufficient to give them an aëriform ſtate, hold it with ſo much force, that neither preſſure, nor the contact of colder bodies, can take it away, and convert them into a liquid; in that caſe they are ſaid to be *permanently elaſtic fluids*, otherwiſe they are called *vapours*.

When caloric is communicated to a body, that body will abſorb as much of it as its peculiar affinity will enable it to abſorb, and the reſt will tend to expand itſelf equally through all the ſurrounding bodies.—The former portion is called *combined caloric*, and the latter has been called *free caloric*, becauſe its tranſition to other bodies becomes ſenſible from the effects it produces on thoſe bodies; viz. thoſe other bodies are expanded, or ſoftened, or liquified by it. This effect of expanding bodies furniſhes the beſt means of meaſuring heat or free caloric; and the Thermometer acts upon this principle. The quantity of combined caloric is meaſured in the ſame manner as, by analyzing, we ſeparate, and meaſure, the quantity of any other ingredient; viz.

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the vapour of water may become more permanently elaſtic, at leaſt ſo as not to be condenſable into fluid water merely by mechanical preſſure, or cooling.

the given body A is mixed with ſome other body B, that has a greater attraction, or affinity, for A, than A has for caloric; in conſequence of which that latent, or combined caloric of A, is ſeparated from it, and becomes free caloric, or ſenſible heat; and its quantity may be meaſured from the effect it produces on the Thermometer, or upon other contiguous bodies.

The *electric fluid* ſeems to be another remarkable agent in nature. Its action ſeems to be very extenſive. It has no perceivable weight, nor can we exhibit it by itſelf. It paſſes more or leſs freely through certain bodies, and not at all, or perhaps difficultly, through others. Hence the former bodies are called *conductors*, and the latter *non-conductors*, of electricity. It is developed or abſorbed in a variety of natural and artificial proceſſes: hence it ſeems to have peculiar affinities; but the facts which have been diſcovered, though numerous, do not enable us to form any diſtinct and comprehenſive notions with reſpect to its real and general agency.

The magnetic fluid is much more hypothetical, and more partial in its action, than any of the former. This is ſuppoſed to be a fluid which, excepting in very few caſes, affects iron alone, or ſuch bodies as contain iron, and produces thoſe effects which are called *magnetic*, and which are all reducible to two, viz. to an attraction (not an attraction of affinity) between certain parts of ferruginous bodies, and to a repulſion between certain other parts of the ſame bodies.—We have no knowledge of this fluid entering into combination with any body, nor of its producing any other effect.

Of thoſe four natural agents, viz. heat, light, electricity, and magnetiſm, particular notice will be taken in the next volume. What has been already ſaid concerning their nature, is ſufficient to illuſtrate the ſubject of the remaining pages of the preſent volume.

There ſeem to be only three principal and permanently elaſtic fluids in nature, each of which conſiſts of a ſimple ſubſtance combined with caloric, and, probably, with light:—they are called *oxygen air*, *hydrogen gas*, and *azotic gas*, or *nitrogen gas* *; and their baſes, or peculiar conſtituents, independent of the caloric and light, are called *oxygen*, *hydrogen*, and *azote*, or *nitrogen*. But there are ſeveral other aërial fluids, ſome of which are combinations of the above-mentioned three, with other ſubſtances. The following liſt contains their number, their names, and the ingredients of them all, beſides caloric and light.

Oxygen gas, or *pure vital air*.

Atmoſpheric air, conſiſting of about 28 parts of

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* The name *air* has been more particularly given to the reſpirable fluids; whereas the word *gas* is a more general appellation for permanently elaſtic fluids, particularly for thoſe of a ſuffocating quality.

oxygen

oxygen air, and 72 of azotic gas.—Thoſe two fluids are fit for reſpiration, and, of courſe, for ſupporting animal life; all the reſt being ſuffocating, and unfit.

Azotic gas.

Nitrous gas, conſiſting of azote, combined with a little oxygen.

Oxygenated muriatic gas, conſiſting of muriatic acid, ſurcharged with oxygen and deprived of water. This is the only aërial fluid which has a little colour, viz. a greeniſh-yellow tinge. All the others are colourleſs.

Carbonic acid gas, conſiſting of carbon diſſolved in oxygen. This, and eſpecially the four following, are abſorbible in great quantities by water.

Muriatic acid gas, being muriatic acid deprived of its ſuperabundant water.

Sulphurous acid gas, being ſulphuric acid that has loſt part of its oxygen, and alſo loſt its ſuperabundant water.

Fluoric acid gas, being fluoric acid deprived of its ſuperabundant water.

Ammoniacal gas, being ammonia (or cauſtic volatile alkali) deprived of its ſuperabundant water.

Hydrogen gas. This and the four following, are inflammable.

Sulphurated hydrogen gas, (or *hepatic gas*) conſiſting of ſulphur diſſolved in hydrogen.

Phoſphorated hydrogen gas, conſiſting of phoſphorus diſſolved in hydrogen.

Carbonated hydrogen gas, conſiſting of hydrogen, and the baſe of carbonic acid gas.

Hydrogen gas of marſhes, conſiſting of hydrogen and different proportions of azote.

Thoſe are the principal elaſtic fluids, or thoſe which occur more commonly. Mixtures of two or more of them are infinite in number; but the ingredients may be ſeparated more or leſs by various means, and thus their quantities may be aſcertained. Thoſe means muſt be derived from their peculiar properties; for inſtance, if a mixt elaſtic fluid be agitated in water, the water will abſorb that which is of a ſaline quality, and will leave the other by itſelf. Then the latter, by the application of a lighted candle, will ſhew whether it be inflammable, or capable of aſſiſting combuſtion, or incapable of it, &c.

The purity of the atmoſpherical fluid, which is various at different times and places, is tried by expoſing to a determined quantity of it, ſuch ſubſtances as have great affinity for the oxygen part; for by this means the atmoſpheric air is decompoſed, the oxygen combines with the other ſubſtance, and the azotic gas remains by itſelf; and its quantity determines the purity of the air, or rather the ratio of azote to oxygen; for the air may be rendered unfit for reſpiration by the ſuſpenſion of other ſubſtances, which do not diminiſh the proportion of oxygen in it.

Carbon, or the carbonaceous principle, is pure charcoal,

charcoal, and ſeems to be a ſimple ſubſtance; for it has never been decompoſed. It exiſts in vegetables, as alſo in animal bodies, and may be ſeparated from the oily and volatile principles by diſtillation, as alſo from the ſalts, by waſhing in pure water.

Sulphur ſeems to be a pure ſubſtance. It exiſts principally amongſt minerals, but ſome of it alſo exiſts in vegetable and animal bodies.

Phoſphorus cannot be decompoſed, and of courſe it may be conſidered as a ſimple ſubſtance.

The burning of phoſphorous, of ſulphur, or of carbon, is not a decompoſition of thoſe bodies, but a combination of thoſe bodies with oxygen, which combination increaſes their weight, renders them miſcible with water, and gives them a ſtrong ſour taſte; viz. they become the *phoſphoric acid*, the *ſulphuric acid*, and the *carbonic acid*; ſo that the acceſſion of oxygen turns them into acids; and hence the oxygen derives its name, which, from its Greek origin, means the *acidifying principle.*— The heat and the light which attend the combuſtion, are derived from the oxygen air which depoſits them, when it loſes its aëriform ſtate, and combines with the phoſphorous, or the ſulphur, or the carbon.

In a ſimilar manner oxygen combines with a variety of other ſubſtances, which combination is called *oxidation*; and the compounds, according to the different proportions of oxygen, have different properties, and different generic names, beſides

ſides the names of the peculiar radicals with which the oxygen is combined*.

The combination of a very ſmall quantity of oxygen conſtitutes what are called *oxides*; with more oxygen the combinations are called *weak acids*; with a quantity ſtill greater of oxygen, the denominations are made to terminate in *ous*, viz. we ſay the *nitrous acid*, the *ſulphurous acid*, &c. When the quantity of oxygen is as much as will completely ſaturate the baſes, the appellations terminate in *ic*; viz. we ſay the *nitric acid*, the *ſulphuric acid*, &c. and, laſtly, when the combinations contain more oxygen than is neceſſary for their ſaturation, then thoſe ſtates are expreſſed by annexing the word *oxygenated* to the peculiar name of the acid.

All the articles, which follow *phoſphorus* in the liſt of pages 15 and 16, as far as the *zoonic radical*, are capable of abſorbing oxygen enough to give them an acid taſte, as alſo other properties peculiar to acids; hence they form the various acids, which derive their appellations from the names of their peculiar radicals †.

The

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* Some of thoſe radicals (as the muriatic) are only reckoned ſuch from analogy; for they cannot be exhibited in an uncombined ſtate, like *ſulphur* and *phoſphorus*, which are the radicals of the ſulphuric, and of the phoſphoric, acids.

† The acids are generally divided into *mineral*, *vegetable*, and

The articles of the liſt, &c. which follow the zoonic radical, and as far as *gold*, are called *metallic ſubſtances:*

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and *animal*, acids, according to the nature of their radicals. Acids in general have a ſour taſte, have a powerful affinity for alkalies, and redden certain blue vegetable colours.

The mineral acids are the ſulphuric (formerly called the *vitriolic*) acid, the nitric acid, the muriatic acid (formerly called the *marine acid*), the carbonic acid (formerly called the *aërial acid*, or *fixed air*), the phoſphoric acid, which is likewiſe an animal acid, it being found amongſt animal matters, as well as among minerals, the acid of borax, the fluoric acid, the arſenic acid, the molybdic acid, the tungſtenic acid, and the cromic acid. Theſe laſt four are alſo called *metallic* acids.

Every one of the vegetable acids ſeems to have a compound baſis, conſiſting of carbon and hydrogen, but in different proportions. All their radicals may be decompoſed, but they cannot be compounded from ſimpler ſubſtances; and it is on account of this circumſtance that they are reckoned amongſt the primitive ſubſtances. They are diſtinguiſhed from each other by their peculiar affinities for alkalies, or earths, or metallic ſubſtances. The vegetable acids are the acetic, or vinegar, the acid of tartar, the empyreumatic acid of tartar, the oxalic or acid of ſorrel, the acid of galls, the citric or lemon acid, the malic or acid of apples, the benzoic, or the acid of the flowers of benjamin, the empyreumatic acid of wood, the empyreumatic acid of ſugar, the acid of camphor, and the ſuberic or acid of cork.

The animal acids, excepting the phoſphoric, likewiſe ſeem to have their baſes or radicals compounded of carbon,

hydrogen,

ſubſtances: they cannot combine with as much oxygen as the preceding radicals; hence they can only form oxides, formerly called *metallic calces*; yet from thoſe we muſt except the firſt four, viz. arſenic, molibdenite, &c. which can combine with ſo much oxygen, as actually to acquire ſome evident acid properties. The others alſo have different affinities for oxygen. Thoſe which come firſt in the liſt, have a greater affinity for oxygen than thoſe which follow. The laſt four, viz. mercury, ſilver, platina, and gold, have leſs affinity for oxygen than any of the reſt; for the oxides of thoſe metals may be deprived of the oxygen; that is, may be *reduced* into their ſimple or metallic ſtates, by heat alone; whereas the oxides of the other metallic ſubſtances, cannot be deprived of their oxygen by heat alone, but the proceſs muſt be aſſiſted by the contact of

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hydrogen, phoſphorus, and azote, in different numbers and different proportions. The animal acids are, the acid of milk, the acid of ſugar of milk, the formic or acid of ants, the pruſſic acid, viz. the colouring matter of Pruſſian blue, which is obtained from dried blood, hoofs, &c. the ſebacic or acid of fat, the bombic or acid of ſilk-worms, the laccic or the acid of waxy matter, and the zoonic, or the acid extracted from animal matter by means of lime. Thoſe acids are alſo diſtinguiſhed from each other by their peculiar affinities, and their baſes or radicals may be decompounded, but cannot be compounded from ſimpler ſubſtances.

ſome other ſubſtance, which has a greater affinity for oxygen*.

The

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* The metallic ſubſtances are diſtinguiſhed by their abſolute opacity, great ſpecific gravity, brilliancy, and ductility; but this laſt property is very imperfectly poſſeſſed by all thoſe which precede iron in the liſt, and which are, on that account, called *ſemi-metals*. All the metallic ſubſtances become liquid in certain peculiar degrees of heat. They have different ſpecific gravities, (ſee the table of Specific Gravity in page 75, and following), different colours, and different degrees of ductility; they have alſo peculiar affinities for other ſubſtances. We ſhall briefly ſubjoin a few of their more remarkable characteriſtic properties; commencing with the moſt perfect of the metals, and which has the leaſt affinity for oxygen.

Gold has an orange or reddiſh yellow colour; is the heavieſt metallic ſubſtance, platina excepted; it melts at about 5237° of Fahrenheit's Thermometer; is the moſt perfect, ductile, tenacious, and unchangeable of all the known metals. Its proper ſolvents are the *nitro-muriatic acid*, (*aqua regia*), and the oxy-muriatic acid.

Platina. Its colour is white; it is the moſt ponderous metal. By itſelf it reſiſts the fire of ordinary furnaces, and can only be fuſed by means of powerful burning glaſſes, or in a fire urged by a current of oxygen air. It may be alloyed with moſt metallic ſubſtances, and in that ſtate may be fuſed with much greater facility. It is not affected by the action of the atmoſphere. Its proper ſolvents are the ſame as thoſe of gold.

Silver has a pure white colour. It is malleable and very ductile, though not quite ſo much as gold. It fuſes at

about

The ſeven ſubſtances which follow gold in the liſt, are called *earths*, or *earthy ſubſtances* ; viz. *ſilica*,
or

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about 4717° of Fahrenheit's Thermometer. It may be alloyed with ſeveral metals. It is diſſolved by various acids, eſpecially by the nitric.

Mercury. Its colour is like that of bright poliſhed ſilver. It is the heavieſt metallic ſubſtance next to gold and platina. It is a ſolid in a temperature under the 72° below friezing water. It is a liquid between that degree and 600° of Fahrenheit's Thermometer; but above that degree it becomes a vapour, or an elaſtic fluid. The nitric acid is its beſt ſolvent.

Copper has a browniſh-red colour ; is malleable, flexible, and ductile ; though not ſo much as ſilver. It melts at 4587° of Fahrenheit's Thermometer. By expoſure to the fire it changes colour, and becomes firſt blue, then yellow, and laſtly violet. It gives a greeniſh-blue tinge to the flame of burning coals. It is diſſoluble, more or leſs, in moſt of the acids. With the acetous acid it forms *verdigris*. Copper may be united to moſt metallic ſubſtances, forming various uſeful compounds.

Lead has a blueiſh white colour, and is the heavieſt metal, after gold, platina, and mercury. It melts at 540°. Its ſurface is readily oxidated. It is diſſolved by moſt acids. Its oxides form various uſeful colouring pigments.

Tin comes neareſt to the colour of ſilver ; but its ſurface is ſoon tarniſhed. It is very ductile, flexible, and when bent crackles in a peculiar manner. It fuſes at 410°, and is pretty readily oxidated. It is diſſolved more or leſs by moſt acids.

Iron is of a pale, ſomewhat blueiſh-grey, colour. It is the
moſt

or *ſilex, argil* or *alumine, baryt* or *barites, ſtrontian, lime,*

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moſt uſeful, moſt abundant, and the moſt diffuſed, metal in nature. Iron (excepting a few equivocal caſes) is the only metal ſuſceptible of magnetiſm. It is eaſily oxidated, and its colour changes according to the degree of oxygenation. It is found combined with a variety of ſubſtances, from ſome of which it cannot be ſeparated without very great difficulty; hence we have iron of different qualities and of different fuſibility. Caſt iron melts at about 17977°. Its union with carbon forms *ſteel.*

Zinc. Its colour is between the colour of ſilver and that of lead. It has very little ductility. It fuſes as ſoon as it becomes red hot, (viz. when the heat is about 1070°) then with the acceſs of air it inflames and ſublimes in white flocks of oxide, called *philoſophical wool*, or *pompholix.* It unites with ſeveral metals. With copper it forms *braſs.*

Antimony is a whitiſh brilliant ſemi-metal, not eaſy of fuſion, but when fuſed it emits a white fume called *argentine ſnow*, or *flowers of antimony.* The ſtate in which this ſemi-metal is generally ſeen in commerce, and in which ſtate it is improperly called *antimony*, is in combination with ſulphur.

Biſmuth (otherwiſe called *tin-glaſs*) is white, with a ſhade of red inclining to yellow. By means of the hammer it may be reduced into powder. It fuſes eaſier than tin. When expoſed to a ſtrong heat, it burns with a blue flame, and ſublimes in a yellowiſh ſmoke, which condenſes and forms the *flowers of biſmuth.* The nitric acid is its beſt ſolvent, Its combinations with various metallic ſubſtances, form pewter, ſolders, printer's types, &c.

Cobalt is white, inclining to bluiſh grey, and, when tarniſhed, to red. In a red heat it is malleable to a certain degree;

lime, *magneſia*, *jargonia* or *zirgonia*; to which we ſhall

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gree; and, when pure, it is as difficultly fuſed as iron. It is not eaſily oxidated. When expoſed to the fire in conjunction with borax, or ſoda, &c. and earthy ſubſtances, it tinges them blue. Its oxide, fuſed with ſand and pot-aſh, forms a blue glaſs, which, when finely pounded, is called *ſmalt*.

Nickel, in its pure ſtate, has a greyiſh white colour. It is magnetic in a very ſmall degree; hence it is thought to contain iron. It is malleable in a conſiderable degree, and is ſlowly oxidated in a ſtrong heat. The nitric acid is its beſt ſolvent.

Mangancſe is of a greyiſh white colour, but it is ſo eaſily oxidated, as to be readily darkened by expoſure to the air; it falls into powder, and becomes a perfect oxide of a dark brown or black colour. Indeed it is in that ſtate that we always find it. This oxide, expoſed to a pretty ſtrong heat in proper veſſels, yields a very great quantity of oxygen air. This metallic ſubſtance is leſs fuſible than iron, and unites, by fuſion, with every one of the metals, except mercury.

Uranite is of a dark ſteel or iron grey colour. Nitrous acid diſſolves it; but its oxide is inſoluble in alkalies, which circumſtance diſtinguiſhes it from the oxide of tungſten, which it reſembles in colour.

Sylvanite, or *Tellurite*, is of a dark grey colour, inclining to red. It has a conſiderable degree of ductility and malleability; is the moſt fuſible metallic body, excepting mercury. It readily unites with mercury and ſulphur. It is diſſoluble in nitrous acid, in the ſulphuric acid, and in nitro-muriatic acid.

Titanite is imperfectly known. Its oxide, which was formerly taken for a *red ſhorl*, is but ſparingly found united to

ſhall add two more which have been lately diſco-
vered

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to other minerals, and from certain phenomena, which attend its diſſolutions and precipitations, it appears to be the oxide of a new metallic ſubſtance, to which the name of *titanite* has been given; but it ſeems that it was never fairly reduced to a metallic ſtate.

Chrome has a whitiſh grey, ſhining, appearance. It is obtained from a mineral called *Siberian red lead.* It yields a particular acid, of a ruby red colour, which contains two thirds of its weight of oxygen.

Tungſten is ſuppoſed to be the oxide of a particular metallic ſubſtance; for it does not appear to have ever been fairly reduced to a metallic ſtate. It is of a ſteel grey colour, very hard and brittle. It affords a peculiar acid.

Molybdenite is a ſubſtance of a metallic luſtre, which marks paper like *plumbago* (*black lead*). It is oxidated in a red heat, but it cannot be fuſed without a very powerful fire. Its white or red oxide gives evident marks of acid properties.

Arſenic is naturally white, inclining to blue; but it ſpeedily becomes pale yellow, and then greyiſh black by expoſure to the atmoſphere. In a metallic ſtate arſenic is of a blackiſh grey colour; it is brittle, and in its fracture reſembles ſteel. If arſenic be placed upon burning coals, it burns with a blueiſh white flame, and is volatilized into a white oxide, which attaches itſelf to the chimney, &c. By this means arſenic is extracted from various minerals with which it is found combined. This oxide, which is fuſible in water, is the *white arſenic* of commerce. This volatilized oxide has a ſmell reſembling that of garlic, and is exceedingly dangerous to animals. Arſenic by itſelf fuſes difficultly, but by fuſion it may be united to moſt vered in ſmall quantities, viz. *glucine*, and *aguſtine* *.

The

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metals. When ſaturated with oxygen, it conſtitutes an acid which may exiſt in a concrete form, but it readily attracts moiſture from the atmoſphere, and thereby becomes a fluid.

* The earths are dry, brittle, inodorous, uninflammable, and ſparingly ſoluble in water.

Silica is the earth which forms the principal ingredient of flints, rock cryſtal, and ſeveral gems. It is rough, and when finely pounded, a very minute quantity of it may be kept diſſolved in water. The only acid which acts upon it, is the fluoric. It is infuſible by itſelf; but in a ſtrong heat the fixed alkalies fuſe it readily, and form glaſs.

Argil, or *pure clay*, otherwiſe called *alumine*, (for with the ſulphuric acid it forms alum) in its pure ſtate is white, ſmooth, of an unctuous feel, and is diffuſible in water. When heated it diminiſhes in bulk, is hardened, and is rendered indiffuſible in water. It may be hardened ſo as to ſtrike fire with ſteel. This moſt uſeful property enables us to form bricks, pots, and a variety of utenſils, commonly known under the name of *earthen-ware*.

Baryt, or *Ponderous Earth*, (from its conſiderable ſpecific gravity) is infuſible when pure. Cold water diſſolves a 25th part, and boiling water one half, of its weight. It is ſoluble in alcohol, and is highly poiſonous. See les Annales de Chimie XXI. It has a greater affinity for muriatic acid, than any of the other earths, or the alkalies.

Strontian, when pure, is not fuſible in the fire, but it only glitters with a phoſphoric flame; it may however be fuſed in conjunction with moſt of the other earths. It is

diſſolved

The laſt three articles of the liſt are called *alkalies*, they have a peculiar taſte as well as other peculiar properties. Pot-aſh and ſoda are called *fixed alkalies*, becauſe they cannot be rendered volatile by

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diſſolved readily in the nitric and muriatic acids; and forms, by the addition of the ſulphuric acid, an inſoluble precipitate.

Lime, when pure, is called *quick lime*, or *pure calcareous earth*. Is infuſible by itſelf, but it may be fuſed in conjunction with ſilica and argil. Lime is purified by long expoſure to a ſtrong heat, by which means it becomes white, moderately hard and brittle. It has a hot burning taſte, renders violets green, and corrodes animal and vegetable ſubſtances. By the application of water it becomes hot, burſts, and becomes *ſlaked lime*, which, when mixed with ſand, or dry mould, &c. forms the mortar commonly uſed for building. Slaked lime will be found to have abſorbed 287 grains of water for every 1000 grains of its original weight. Water cannot hold in ſolution more than one 700dth part of its weight of lime, and in that ſtate it is called *lime water*.

Magneſia, when pure, is white and very light. It combines with all the acids. It is infuſible by itſelf.

Jargonia is a peculiar earth obtained from two gems; viz. the *jargon* and the *hyacinth*. It is inſoluble in water. In hardneſs and roughneſs it reſembles ſilica. It is infuſible by itſelf. It unites with the nitric, the carbonic, and the ſulphuric, acids.

Glucine is ſuppoſed to be a peculiar earth obtained from two gems; viz. the *beryl*, or *aqua marina*, and the *emerald*.

by means of heat; — ammoniac is a *volatile alkali* *.

But it muſt be obſerved, that the alkalies are placed in the liſt of ſimple ſubſtances, rather becauſe they form a particular claſs of bodies, which are endued with remarkable and peculiar properties; for they ſeem to be compounds of ſimpler ſubſtances. Indeed, the ammoniac has been proved to conſiſt of 807 parts of azote, and 193 parts of hydrogen; alſo the two fixed alkalies are ſtrongly ſuſpected of being formed from a combination of azote with ſome unknown baſes.

The three alkalies, the acids, and the combinations, in which they enter in ſufficient quantities, are called *ſalts*, or *ſaline ſubſtances*; for a *ſaline ſubſtance*, in its extended chemical ſenſe, means a ſubſtance that has ſome taſte, and is ſoluble in water.

Thus we have endeavoured to give ſome idea of the primitive, or elementary ſubſtances; ſuch as may

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Aguſtine is ſuppoſed to be a peculiar earth obtained from a mineral that reſembles the beryl. It is not ſoluble in water, and it becomes hard in the fire.

* Alkalies have an acrid, urinous taſte; change the vegetable blue colours into a green; combine with acids, and form neutral ſalts; viz. ſalts that have neither the properties of acids, nor of alkalies. As the alkalies appear to be derived principally from azote, therefore azote has been alſo called the *alkaligen principle*.

may be deemed ſufficient for a ſtudent of natural philoſophy. A full account of their properties, affinities, combinations, &c. will be found in various recent publications written profeſſedly on the ſubject of chemiſtry *.

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* See Lavoiſier's Elements of Chemiſtry. Jacquin's Elements of Chemiſtry. Briſſon's Phyſical Principles of Chemiſtry. Fourcroy's Chemiſtry. Gren's Principles of Modern Chemiſtry. Lagrange's Manual of a Courſe of Chemiſtry; and ſeveral other large works: to which may be added, a very uſeful little book; viz. Parkinſon's Chemical Pocket Book, or Memoranda Chemica.

CHAPTER XVII.

OF CHEMICAL PROCESSES.

IT is perhaps ſcarcely ſuſpected by moſt of my readers, that almoſt every phenomenon, which takes place about us, and which is attended with ſome change of property in the bodies concerned, is in fact a chemical proceſs; viz. it does actually depend upon, and is regulated by, the laws of affinity. Heating, cooling, fires, and every ſort of combuſtion; our reſpiration, our digeſtion, the formation, decompoſition, and ſecretion, of the various animal fluids; evaporations, diſſolutions, and fermentations; the operations carried on in the various arts of dyeing, bleaching, tanning, &c. are all depending on the various affinities of bodies. Infinite is the number and the variety of the particular proceſſes; and even the account of a ſelect number of them, is what fills up many large and learned works. In theſe elements we can only attempt to deſcribe the moſt remarkable of thoſe proceſſes; viz. ſuch as are more general or more intereſting, and which may not only elucidate the general theory of chemiſtry, but may alſo aſſiſt the reader in the inveſtigation of other phenomena *.

Combuſtion, in its modern enlarged ſenſe, means every operation in which oxygen air is decompoſed, its radical; viz. the oxygen, is abſorbed, and its other two components, caloric and light, are ſet at liberty, or enter into other combinations. Therefore reſpiration, the oxydation of metallic bodies, and, in ſhort, the oxidation of all other ſubſtances, are different degrees of combuſtion. Thoſe bodies, which have ſo much affinity for oxygen, as to be able to decompoſe oxygen air, are called *combuſtible bodies*.

When the oxygen air is decompoſed ſlowly, the heat is imperceptible, becauſe the caloric is diſſipated as ſoon as generated. When the decompoſition goes on faſter, the bodies concerned become ſenſibly warm. A quicker decompoſition of the oxyen air heats the bodies ſo as to render them red hot; (this temperature is equal to about 1000° of Fahrenheit's Thermometer) which ſtate is called *ignition*. When the proceſs is attended with the production of certain fluids, as hydrogen, volatile

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* Whoever wiſhes to examine this ſubject at large, may peruſe ſome of the valuable works which are mentioned in the note at the end of the preceding chapter; as alſo a variety of works written expreſſively on the arts of dyeing, bleaching, &c.

oils, &c. and the decompoſition of oxygen air affords a ſufficient developement of caloric; then the above-mentioned fluids themſelves are ignited and decompoſed, which conſtitutes the *flame*, and is thence called *inflammation.* The quickeſt decompoſition of oxygen air is attended with a very quick extrication of caloric, a ſudden expanſion of the contiguous bodies, and of courſe with a ſudden noiſe; hence it is called *detonation.* A quick ſucceſſion of little detonations, is called *decrepitation*, or *deflagration.*

Combuſtions are generally attended with the decompoſition and formation of ſeveral compounds; viz. the carbon, which naturally exiſts in vegetable and animal ſubſtances, unites with part of the oxygen, and forms *carbonic acid gas*; ſome of the neutral ſalts are decompoſed, and an alkali is left intermixed with what fixed matter remains after the combuſtion, &c.

Two principal facts muſt be particularly remarked in this place. Firſt, that the greateſt part of the heat, which is yielded in combuſtion, comes from the decompoſition of the oxygen air; and ſecondly, that the oxygen air is the general, and the only ſubſtance, which by its decompoſition, &c. can produce combuſtion. In fact, where no oxygen air exiſts, as in vacuo, in azotic gas, in hydrogen gas, &c. there combuſtion cannot take place; an animal cannot reſpire, a metallic body cannot be

oxidated,

oxidated, or in general a combuſtible body cannot burn; for inſtance, a piece of charcoal, expoſed to a ſtrong fire in a cloſe veſſel, will not thereby be altered.

The atmoſpherical air is uſeful for thoſe purpoſes, ſo far as it contains oxygen air. When that portion of oxygen, which is about a quarter of the atmoſpherical fluid, has been more or leſs, or entirely, ſeparated, the remainder will accordingly be found leſs fit, or quite unfit for reſpiration, for combuſtion, &c. Hence will appear the neceſſity of ventilating towns, houſes, ſhips, &c.

If you place a lighted wax taper under a glaſs receiver, which is inverted with its aperture in water, and is ſituated upon the ſhelf of the tub, fig. 8. Plate XVII. you will find that as the flame decompoſes the oxygen air, and of courſe leſs and leſs of that air remains within the receiver, ſo the flame becomes gradually ſmaller, leſs active, and at laſt ceaſes to burn. After the cooling of the apparatus, you will find the water to have riſen within the receiver, and to occupy the place of the decompoſed oxygen air; viz. about one quarter of the original bulk of the common air. The remaining azotic gas is unfit for combuſtion. This gas contains a ſmall quantity of carbonic acid gas, which has been formed by the union of the carbon of the wax with ſome of the oxygen. This carbonic acid gas may be ſeparated from the azotic gas by agitation in lime water, which abſorbs it, and leaves the azotic gas by itſelf*.

If the glaſs receiver be filled with pure oxygen air, the wax taper will be found to burn for a longer time, with a much more active and luminous flame; and the air will diſappear almoſt entirely, excepting only the carbonic acid gas which has been formed, and a ſmall portion of oxygen air which remains mixed with the acid gas.

The moſt active fire which we can poſſibly produce, is obtained by paſſing a current of oxygen air, inſtead of common air, through burning coals, or other combuſtibles.

For the ſupport of animal life, a conſtant ſupply of heat is indiſpenſably neceſſary, and the caloric, which produces that heat, is derived from the decompoſition of oxygen air in the courſe of reſpiration. A certain quantity of carbonated hydrogen gas is ſuppoſed to be diſengaged from the blood in the lungs; the oxygen of the air, which is inſpired,

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* Gun-powder may be fired in vacuo, and compoſitions of gun-powder, nitre, &c. may be made to burn under water; but in thoſe caſes the oxygen, neceſſary for the combuſtion, is afforded by the nitre, or by ſome other ſalt analogous to it. In fact, if nitre be put by itſelf in an earthenware retort, and the retort be expoſed to a fire ſufficient to render it ſtrongly red hot, or rather white hot, the nitre will yield abundance of oxygen air, which may be received in a receiver full of, and inverted in, water.

combines with the hydrogen, and with the carbon of the above-mentioned gas, and parts with its caloric; thus carbonic acid gas and water is produced, (for, as it will be ſhewn in the ſequel, water conſiſts of oxygen and hydrogen). The caloric which is diſengaged in this proceſs, expands itſelf through the adjoining parts, and ſupplies the heat neceſſary for animal life.

If the atmoſpherical fluid conſiſted entirely of oxygen air, then a much greater quantity of heat would be produced by reſpiration than is neceſſary for the ſupport of animal life, the combuſtion of bodies would likewiſe proceed too rapidly, and of courſe decompoſitions of every ſort would go on with uſeleſs precipitation; hence we may thankfully admire the juſt and temperate conſtitution of the atmoſpherical air.

One of the moſt remarkable diſcoveries of modern times, is the decompoſition and compoſition of water, which was formerly conſidered as an elementary or ſimple ſubſtance. This decompoſition has been effected two ways principally; viz. by placing the vapour of water in contact with certain ignited bodies, or by means of electricity. The moſt ſatisfactory methods of decompoſing, and of compoſing it, are clearly deſcribed by M. Briſſon, in the following words:

1. " A tube of common glaſs, EF, fig. 11. Plate XVII. well annealed, and difficult to be fuſed,

fuſed, about ¾ of an inch in diameter *, was placed acroſs a furnace CFED, in a poſition ſomewhat inclined, and to its upper extremity was adapted a glaſs retort A, containing a known quantity of diſtilled water, and reſting on a furnace V V. To the lower extremity of the glaſs tube F, was applied a worm S S, connected with the double tubulated flaſk H; and to the other aperture was adapted a bent glaſs tube K K, deſtined to convey the gas to an apparatus proper for determining the quality and quantity of it. When the whole was thus arranged, a fire was kindled in the furnace CFED, and maintained in ſuch a manner as to bring the glaſs tube EF to a red heat, but without fuſing it: at the ſame time, as much fire was maintained in the furnace VVXX, as to keep the water in the retort A, in a continual ſtate of ebullition.

" In proportion as the water in the retort A, aſſumed the ſtate of vapour by ebullition, it filled the interior part of the tube EF, and expelled the atmoſpheric air, which was evacuated by the worm S S, and the tube K K. The ſteam of the water was afterwards condenſed by cooling in the worm SS, and fell, drop by drop, in the ſtate of water,

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* Such tube muſt be luted; viz. covered over with a mixture of clay and pounded earthen-ware; alſo it muſt be ſupported in one or more places, that it may not bend when ſoftened by the heat.

into the tubulated flaſk H. When the whole of the water in the retort A, was evaporated, and the liquor in the veſſel had been ſuffered to drain off completely, there was found in the flaſk H, a quantity of water exactly equal to that which was in the retort A; and there had been no diſengagement of any gas; ſo that this operation was merely a common diſtillation, which gave abſolutely the ſame reſult as if the water had never been brought to a ſtate of incondeſcence in paſſing through the glaſs tube EF.

2. "Every thing being arranged as in the preceding experiment, 28 grains of charcoal reduced to fragments of a moderate ſize, and which had been previouſly expoſed for a long time to a white heat in cloſe veſſels, were introduced into the glaſs tube EF. The operation was then conducted as before, and the water in the retort A, kept in a continual ſtate of ebullition, till it was totally evaporated.

"The water in the retort A, was diſtilled, as in the preceding experiment; and being condenſed in the worm SS, had fallen, drop by drop, into the flaſk H; but at the ſame time there had been diſengaged a conſiderable quantity of gas, which eſcaped through the tube K K, and was collected in a proper apparatus. When the operation was finiſhed, there was found nothing in the tube E F, but a few aſhes; and the 28 grains of charcoal had totally diſappeared.

"The

" The gaſes diſengaged were found to weigh altogether 113,7 grains.

" There were found two different kinds of gas; viz. 144 cubic inches of carbonic acid gas, weighing 100 grains, and 380 cubic inches of a very light gas, weighing 13,7 grains. This laſt gas took fire on being applied to a lighted body in contact with the air.

" In examining afterwards the weight of the water which had paſſed into the flaſk, it was found leſs than that in the retort A, by 85,7 grains. In this experiment, therefore, 85,7 grains of water, and 28 grains of charcoal, formed carbonic acid gas, equal to 100 grains, and a peculiar gas ſuſceptible of inflammation, equal to 13,7 grains.

" We have already ſaid, that to form 100 grains of carbonic acid gas, 72 grains of oxygen muſt be united to 28 grains of charcoal or carbon. The 28 grains of charcoal put into the glaſs tube E F, took, therefore, from the water, 72 grains of oxygen, ſince there was formed carbonic acid equal to 100 grains.

" It appears therefore that 85,7 grains of water are compoſed of 72 grains of oxygen, and 13,7 grains of a ſubſtance, forming the baſe of a gas ſuſceptible of inflammation.

3. " The apparatus being arranged as above, inſtead of the 28 grains of charcoal, 274 grains of thin ſhavings of iron, rolled up in a ſpiral form, were introduced into the tube EF: the tube was then brought to a red heat as

as before; and in the like manner the whole of the water in the retort A, was made to evaporate.

"In this experiment there was diſengaged only one kind of gas which was inflammable: there was obtained of it about 406 cubic inches, weighing 15 grains. The 274 grains of iron, put into the tube E F, were found to weigh above what they did when introduced, 85 grains, and the water firſt employed was diminiſhed 100 grains.

"The volume of theſe iron ſhavings was found to be greatly enlarged. The iron was ſcarcely any longer ſuſceptible of attraction by the magnet; it diſſolved without efferveſcence in acids: in a word, it was in the ſtate of a black oxide, like that which has been burnt in oxygen air.

"In this experiment there was a real oxidation of the iron by the water, entirely ſimilar to that effected in the air by the aid of heat; 100 grains of water were decompoſed, and of theſe 100 grains, 85 united to the iron, to reduce it to the ſtate of black oxide: theſe 85 grains, therefore, were oxygen; the remaining 15 grains combined with caloric, and formed an inflammable gas. It hence follows, that water is compoſed of oxygen, and the baſe of inflammable gas, in the proportion of 85 to 15, or of 17 to 3.

"Water, therefore, beſides oxygen, which is one of its principles, and which is common to it with a great many other ſubſtances, contains another peculiar to itſelf, and which is its conſtituent radical.

This

This radical has been called *hydrogen*; viz. *the generator of water*; and the combination of this radical with caloric, is diſtinguiſhed by the name of *hydrogen gas*.

4. " *Recompoſition of Water.*—Take a wide-mouthed glaſs balloon A, fig. 12. Plate XVII. capable of containing about 30 pints, and cement to its mouth a ſmall plate of copper B C, having above it a cylinder of the ſame metal, *g* D, pierced with three holes to receive three tubes. The firſt of theſe, *h* H, is deſtined to be connected, at its extremity *h*, with an air-pump, in order that the balloon A, may be exhauſted of air. The ſecond tube *g g*, communicates by its extremity M M, with a reſervoir of oxygen gas, and is deſtined to convey it into the ballon A. The third tube *z* D *d*, communicates by the extremity N N, with a reſervoir of hydrogen gas: the extremity *z* of this tube terminates in an aperture ſo ſmall as ſcarcely to admit a very delicate needle. It is through this aperture that the hydrogen gas, contained in the reſervoir, is to paſs into the balloon A. In the next place, the ſmall plate B C is pierced with a fourth hole, into which is inſerted with cement, a glaſs tube, through which paſſes a wire F L, having at its extremity L, a ſmall ball deſtined to make an electric ſpark paſs between the ball and the extremity of the tube that conveys the hydrogen gas into the balloon A. Each of the three tubes has a cock, *r*, *s*, H.

" That the gaſes may be conveyed in a very dry ſtate through the tubes which conduct them into the balloon A, and that they may be deprived of water as much as poſſible, you muſt put into the ſwelled parts M M, and N N, of the tubes, ſome ſalt capable of attracting the moiſture with great activity. Theſe ſalts ſhould be only coarſely pounded, in order that they may not form a maſs, and that the gaſes may paſs freely through the interſtices left between the fragments. You muſt be provided with a ſufficient quantity of very pure oxygen gas, and nearly a triple volume of hydrogen gas, equally pure. To obtain it in this ſtate, and free from all mixture, you muſt extract it from water, decompoſed by means of very pure and ductile iron.

" When every thing has been thus prepared, adapt to the air-pump the tube *b* H, and exhauſt the air in the large balloon A; then fill it with oxygen gas, by means of the tube *g g*, and, by a certain degree of preſſure, force the hydrogen gas to paſs into the balloon A, through the extremity of the tube *z* D *d*; then kindle this gas by means of an electric ſpark; and if you renew the quantity of each of theſe two gaſes, the combuſtion may be continued for a long time.

" In proportion as the combuſtion proceeds, water is depoſited on the internal ſurface of the balloon A: the quantity of this water gradually increaſes, and it unites into large drops, which run down the ſides of the veſſel, and are collected at the bottom of it.

"The ſum of the weights of the gaſes employed, and the weight of the water formed, were found to be equal, within a 200th part. It was by an experiment of the ſame kind, that Lavoiſier aſcertained, that 85 parts, by weight, of oxygen, and 15 parts, alſo by weight, of hydrogen, are required to compoſe an hundred parts of water.

"Theſe phenomena of the decompoſition, and recompoſition of water, are continually effected before our eyes, by the temperature of the atmoſphere, and the agency of compound affinities. It is this decompoſition which gives riſe, at leaſt in a certain degree, to the phenomena of ſpirituous fermentation, thoſe of putrefaction, and thoſe even of vegetation."

The diſſolution of metallic ſubſtances in acids is a very important and remarkable operation of chemiſtry. When a metal is placed in a fluid acid, capable of diſſolving it, heat and efferveſcence (viz. a diſengagement of gas) frequently takes place, and the gas is either the nitrous, or the ſulphurous acid, &c. according to the nature of the acid; the metal gradually diminiſhes in bulk, and at laſt none of it is to be ſeen. The liquor thus loaded with the metallic ſubſtance, is called the *ſolution of that metal*. If an alkali, or certain other ſubſtances, be added to the ſolution, the metallic ſubſtance will be ſeparated from the fluid, and will fall to the bottom of the veſſel. This is called the *precipitate*, and the alkali or other ſubſtance that has been added to the ſolution, is called the *precipitant*. The precipitate, in certain caſes, appears in a metallic ſtate, viz. a powder, or cruſt of the original metal; but it generally appears in the form of a ſalt; viz. quite deſtitute of the metallic appearance: it is, in ſhort, an oxyde of the metal, which may be reduced to a metallic ſtate by depriving it of the oxygen. This laſt proceſs is called *reduction*.

Such are the general phenomena of metallic diſſolutions, and the operations of affinity ſeem to be ſimple and evident; but a cloſer examination of particular diſſolutions, and of the facts which attend each of them, ſhew that the ſubject is much more intricate than it may at firſt ſight appear. In ſhort, it is manifeſted by a variety of experiments, that water is abſolutely neceſſary for every diſſolution; that the water is decompoſed as well as the metal and the acid, and that new compounds are thereby formed. Nearly the ſame thing may be ſaid of reductions; but the number of ingredients of decompoſitions and compoſitions, which act and are produced in every particular caſe, are in part known, and in part gueſſed at. Several elegant experiments in elucidation of this ſubject, which ſhew the above-mentioned neceſſary preſence of water, and a variety of collateral particulars, were furniſhed to the ſcientific world by an ingenious female writer*.

Some idea of the primitive ſubſtances has been given in the preceding chapter; but by far the greater number, if not all, the bodies which naturally occur to our ſenſes, are compounds of ſeveral of the primitive ſubſtances; and their ingredients are in great meaſure to be aſcertained by trials, and by employing other ſimpler and determinate ſubſtances.

Each of the three kingdoms of nature are divided by the chemiſts into ſubordinate diviſions. The mineral is divided into earthy, metallic, ſaline, and bituminous, minerals; of which a general idea has been given in the preceding pages, excepting the bituminous; but theſe ſeem to have a double origin; viz. they ſeem to partake of the mineral and of the vegetable kingdom; for they are found to contain ſeveral of thoſe ingredients which belong principally to vegetables, and perhaps to animals too.

Vegetables ſeem to derive their nouriſhment

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[*] See Mrs. Fulhame's Eſſay on Combuſtion, &c. London 1794. See alſo a ſhort account of Dr. Woodhouſe's Experiments in the Philoſophical Magazine, vol. VII. p. 83. and the Chemical Works mentioned at the end of the preceding chapter, in which the particular phenomena that attend a variety of diſſolutions and reductions will be found.

chiefly from water, which is decompoſed by the powers of vegetation, and its components enter into new combinations. The hydrogen becomes an eſſential principle of plants, and enters into the formation of their reſins, oils, and mucilage. Part of the oxygen forms the acid juices of vegetables, and another part is expelled, when the plants are expoſed to a ſtrong light, in the form of oxygen air; but when the plants are in the dark, as at night, then they give out principally the carbonic acid gas. The common air which ſurrounds a plant contributes to its vegetation, by affording it oxygen in certain caſes, as alſo by depoſiting moiſture upon, or taking it away from, its ſurface, according to circumſtances. Nitrogen is likewiſe abſorbed by plants.

Light, caloric, and carbon, do alſo ſeem to enter into combination with vegetables, and to be neceſſary for their growth.

Moſt of thoſe principles may be extracted, by decompoſition, from all plants; but, beſides thoſe, there are ſeveral others which may be extracted from particular plants.

Though we find that moſt plants are reſolvible into the above-mentioned principles; yet it muſt be acknowledged that the chemical art cannot imitate, or form, any vegetable, no more than it can form any animal, part. The real proportion of the ingredients, the manner of combining them, and probably the neceſſary concurrence of other elements, are far from being aſcertained.

By the decompoſition of plants (I do not mean an extreme decompoſition) ſeveral uſeful ſubſtances are obtained; the moſt remarkable of which we ſhall briefly enumerate.

The *ſap* is the general, or more abundant, fluid of a plant, from which the various peculiar juices, reſins, oils, &c. of the plant, are ſecreted, by the organiſm of the plant and the powers of vegetation.

The *mucilage*, which forms the baſis of moſt vegetable productions, has the following peculiar properties. It is inſipid; is ſoluble in water, but not in alcohol; is coagulable by the action of weak acids, and of metallic ſolutions.

Gum is a conſiſtent ſubſtance, ſoluble in water. It is found concreted in certain places on the ſurface of plants, and is ſuppoſed to be only inſpiſſiated mucilage.

Oils are diſtinguiſhed into *fixed* or *fat oils*; viz. ſuch as contain mucilage, and cannot be rendered volatile without a conſiderable degree of heat; and into *volatile oils*, which contain *aroma*, or the odoriferous part of the plant. By diſtillation oils yield a phlegm, an acid, a fluid, or light oil, a conſiderable quantity of hydro-carbonate gas, carbonic acid gas, and leave in the retort a reſiduum

reſiduum which does not afford any alkali, as the aſhes of moſt vegetables do. The volatile oils afford a greater proportion of hydrogen gas, and the fixed oils a greater proportion of carbonic acid gas; for this gas is in great meaſure derived from the mucilage.

Reſins ſeem to be oils concreted by the combination with oxygen. They are inflammable, ſoluble in alcohol, and in oils, but not in water.

Gum reſins ſeem to be mixtures of mucilage and of reſins; for they are partly ſoluble in water, and partly in alcohol.

Fæcula ſeems to be little different from mucilage. The principal circumſtance, in which they ſeem to differ, is, that fæcula is not ſoluble in cold water.

Vegetable gluten, is an adheſive ſubſtance, obtained principally from the flour of farinaceous plants, by forming a paſte of that flour, and kneading it in water, until it no longer tinges the water.

Sugar is an eſſential ſalt, which may be extracted in various quantities from different plants.

Albuminous Matter of Vegetables, is a flocculent matter, which is extracted from the juice of certain plants, and in ſome meaſure reſembles the white of an egg, whence it has derived its name.

The different acids, which may be obtained from

from vegetables, have already been enumerated in the preceding chapter.

The conſtituent principles of plants have different affinities; but the proportion of thoſe principles in a living plant, is ſuch as to balance their peculiar affinities; and the exceſs or defect of each principle is eaſily expelled or abſorbed by the action of vegetation. But when vegetation ceaſes, then the action of the atmoſphere, which heats or cools, or oxygenates, or dries up, or moiſtens, the vegetable ſubſtances, ſoon diſturbs that juſt proportion of ingredients, and produces a variety of effects. If the vegetable abound only in moiſture, a dry air and ventilation will dry it up; and ſuch is the caſe with wood, ſeeds, &c. When the vegetables are very juicy, and thoſe juices contain a variety of principles, then thoſe principles begin to ſeparate, the heavieſt go to the bottom, the moſt volatile fly away, an inteſtine motion is thereby produced, new combinations take place, &c. This decompoſition in general is called *fermentation*. In different ſtates of it different effects are produced, and from thoſe effects it derives three different names; viz. of *vinous*, *acid*, and *putrid*, *fermentation*.

The *Vinous Fermentation*, or *Spiritous Fermentation*. In order to produce this fermentation, the expreſſed juice of grapes (and the ſame thing with little difference may be ſaid of the juices of ſeveral other fruits) is placed in an open veſſel, or vat, and

and is kept gently warm, as about 70° of Fahrenheit's Thermometer. The liqour ſoon grows turbid, and an inteſtine motion takes place through the whole maſs, attended with a copious diſcharge of carbonic acid gas, and a frothy ſubſtance called *yeaſt*. After a day or two, and ſometimes longer, the phenomena gradually diminiſh, and ceaſe almoſt entirely. In that ſtate the liquor is pretty clear, and will be found to have acquired a vinous taſte and odour; and the thickeſt or more conſiſtent part will be found ſettled at the bottom of the veſſel. Now if the progreſs of diſſolution be ſtopped, which is done by ſeparating the clear liquor from the thick ſediment, by preventing the acceſs of air to it, by placing it in a cooler ſituation, &c. then the liquor remains with little alteration in the ſtate of *wine*. But if the whole be left undiſturbed, the fermentation will paſs on to the next ſtage; viz. to

The acetous Fermentation. This conſiſts in the abſorption of oxygen from the atmoſphere; and the reſult is *vinegar*, or the *acetous acid*.

In the putrid Fermentation the colour of the vegetables changes; they grow pretty hot, and a mixture of gaſes is diſengaged; viz. of azote, hydrogen, carbonic acid, and ammoniacal, gaſes. This proceſs completes the diſſolution of the vegetable ſubſtances.

Wine, or fermented liquors, yield, by diſtillation, an inflammable and odoriferous liquor, called

called *ſpirit of wine*, and, in its pureſt ſtate, *alcohol*.

Alcohol ſeems to be formed from an intimate combination of hydrogen and carbon, and is perfectly miſcible with water.

Alcohol mixed with the ſulphuric, or the nitric, or other acid, and then diſtilled, yields the lighteſt liquid known. This liquid is called *ether*, to which the name of the acid is added; viz. it is called the *ſulphuric*, or the *nitric*, or the *muriatic*, or the *acetic ether*, according to the nature of the acid which has been employed for its production.

Ether ſeems to be formed from a combination of the oxygen of the acid, with the carbon and the hydrogen of the alcohol. It has a peculiar ſmell, is very volatile, and highly inflammable. If ether be mixed with an equal bulk of water, about a quarter of it will be diſſolved by the water; the other three quarters, which are purer than previous to the mixture, will be found to ſwim upon the water.

Animal ſubſtances, whether ſolid or fluid, conſiſt of, for they are reſolvable into, the following principles; viz. *azote*, *carbon*, *hydrogen*, *oxygen*, *phoſphorus*, and *lime*. The various, but unknown, proportions, the number, and the arrangement of thoſe ingredients, conſtitute the blood, the milk, the gall, the bones, the muſcles, the fat, and all the other parts of animal bodies. But with reſpect to the facts which have been aſcertained, or the conjectures which have been offered, relative to the original formation, growth, ſecretion, form, ſituation, and other properties of thoſe animal parts, I muſt unavoidably refer the reader to the works of the anatomical and chemical writers: we ſhall, however, ſubjoin a ſhort account of the natural proceſs of the putrefaction of animal ſubſtances, with which we ſhall cloſe the preſent volume.

An animal, like a vegetable, when deprived of life, begins to undergo a decompoſition or ſeparation of its conſtituent principles; and this decompoſition is aſſiſted and promoted by a moderate warmth, by moiſture, and by the acceſs of air. It muſt be obſerved, however, that animal diſſolution does not go through the vinous and acetic ſtates of fermentation; but it proceeds directly to the putrid, principally on account of its containing more azote and much ammonia; excepting a few animal fluids, which, by proper treatment, may be cauſed to undergo a vinous or acid fermentation.

The colour and the conſiſtence of dead animals firſt begin to diminiſh, and an unpleaſant odour is exhaled. The colour, after having become pale, changes to blue and green, then to dark brown, according as the parts become leſs conſiſtent, and the putrid effluvium becomes more penetrating, nauſeous, and injurious. This production of gaſes gradually increaſes in pungency and variety; and, from the ſeparation of phoſphorous, it is often attended with a phoſphoreſcent light. The maſs of matter,

matter, already become very ſoft, ſwells, and, laſtly, produces carbonic acid gas. When all the moſt volatile parts have been diſengaged, the fixed radicals, containing ſome hydrogen, form a brown, ſoft, earthy matter, which, if left expoſed to the atmoſphere, becomes, in proceſs of time, a powdery pale ſubſtance; but if mixed with mould, forms *ſoil* fit for vegetation.

The putrid proceſs of animal ſubſtances may be checked or prevented by various means, ſuch as placing the ſubſtances in cold ſituations, freezing, drying up the moiſture which is neceſſary for fermentation, introducing reſinous ſubſtances, placing the ſubſtances in ſpirit of wine, &c.

THE END OF VOL. II.

Plate X.

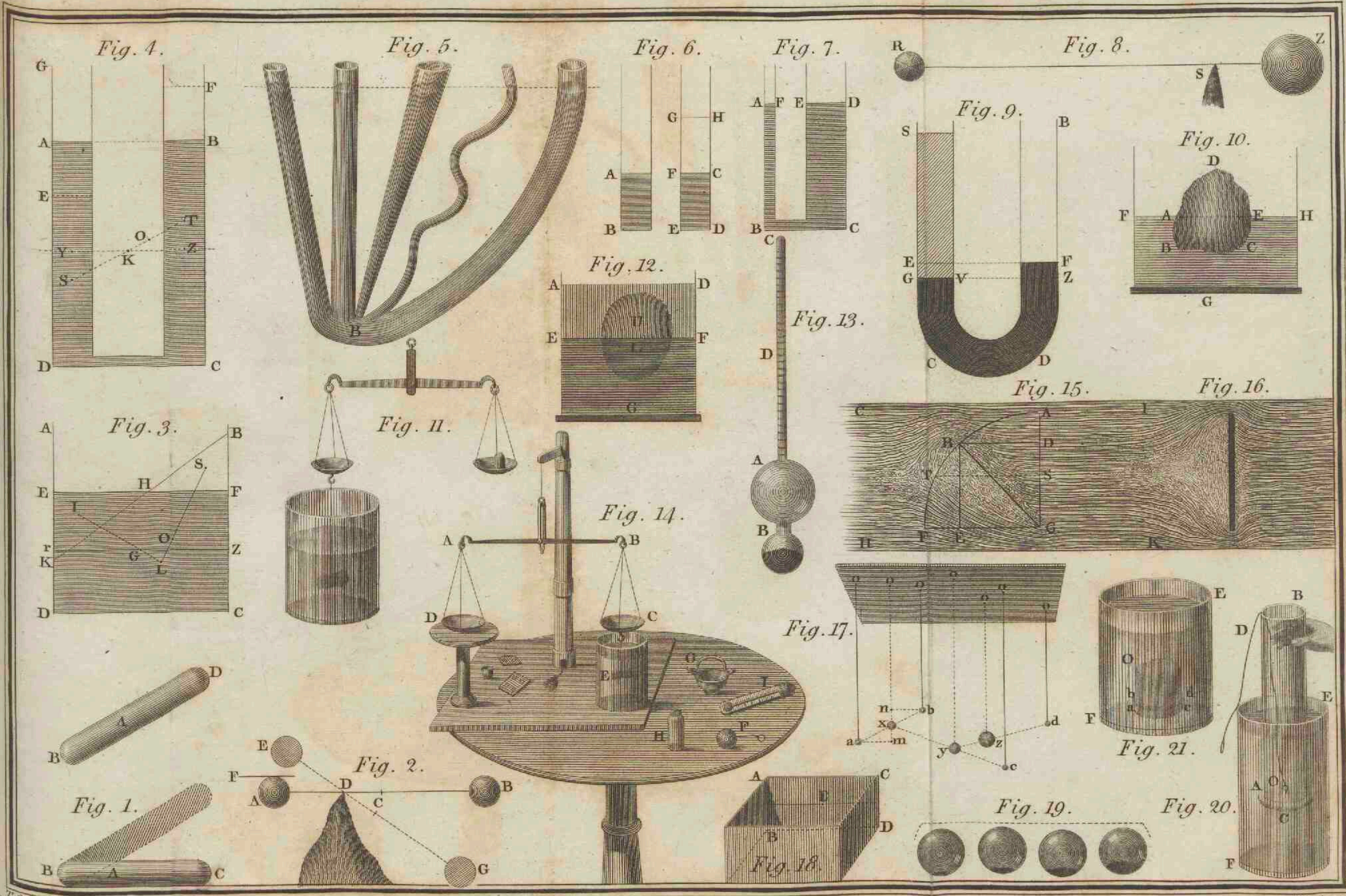

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Plate XI.

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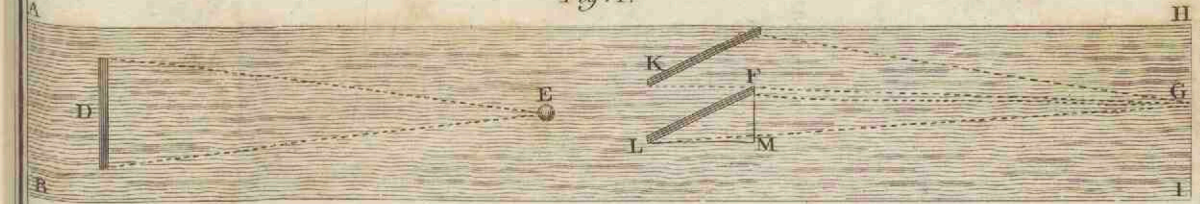

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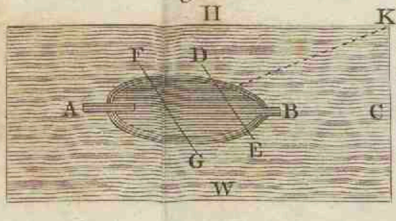

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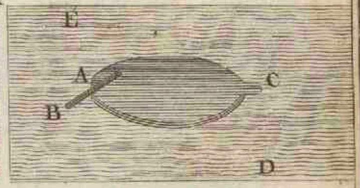

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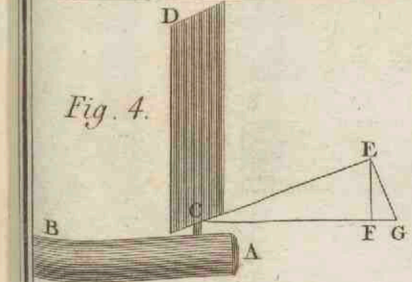

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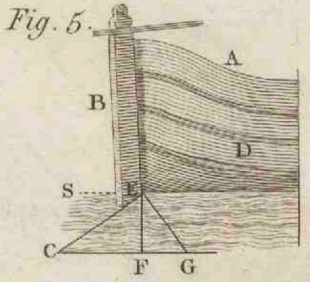

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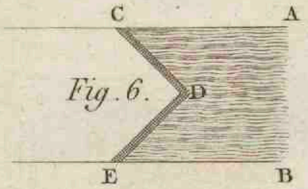

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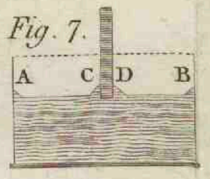

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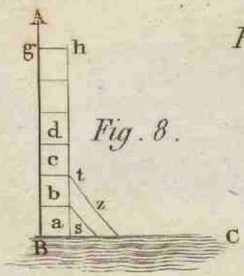

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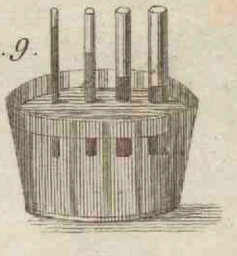

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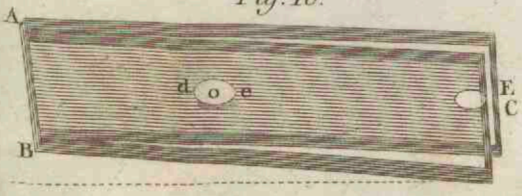

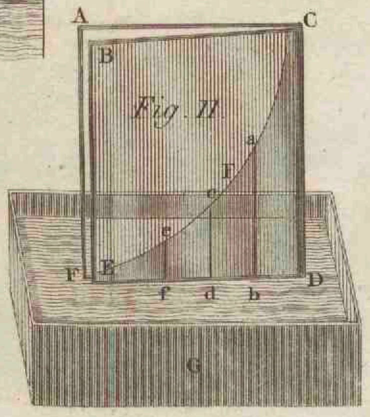

Fig. 15.

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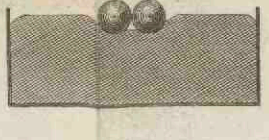
Fig. 18.



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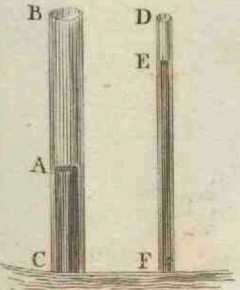

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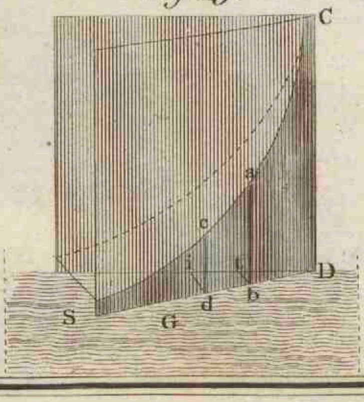

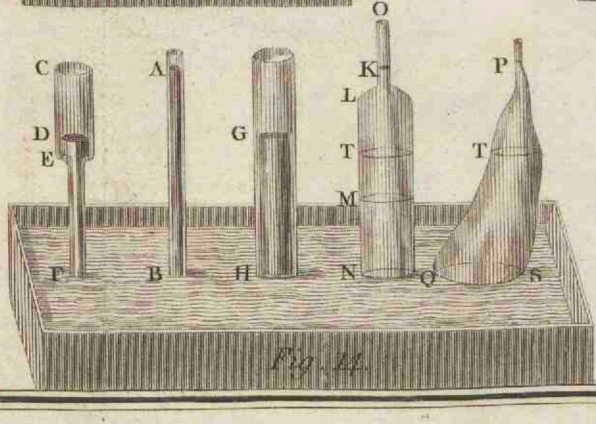

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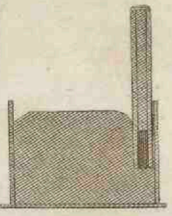

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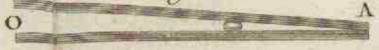

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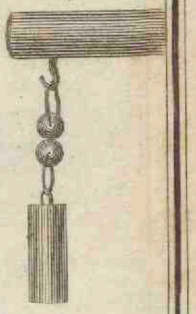

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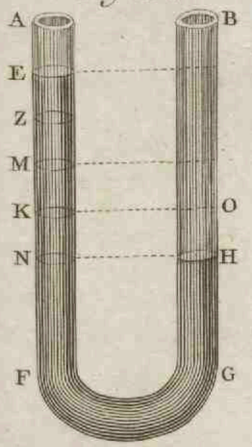

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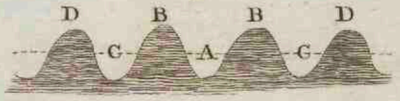

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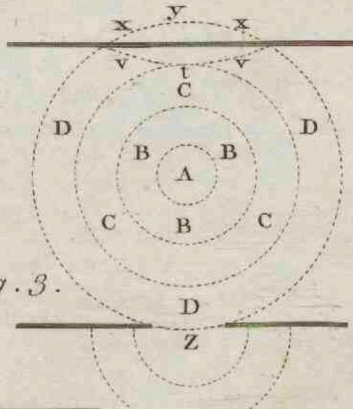

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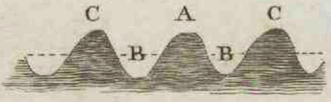

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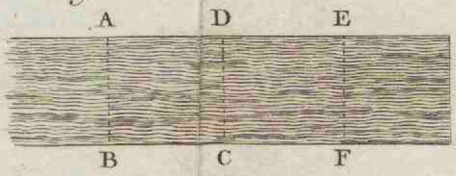

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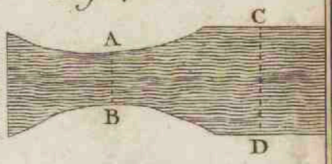

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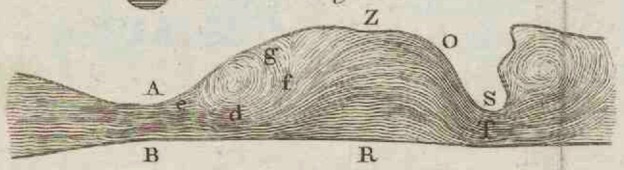

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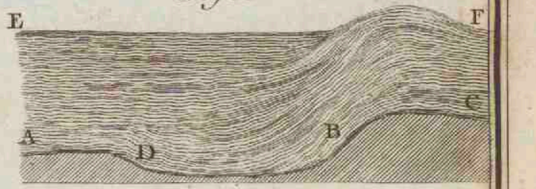

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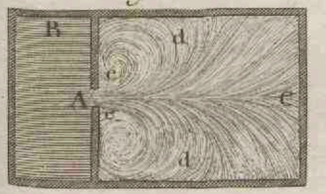

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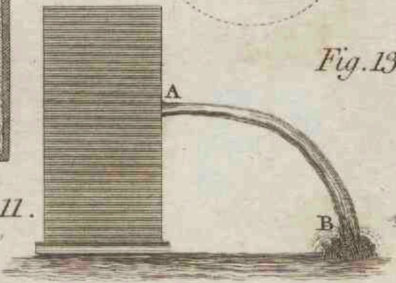

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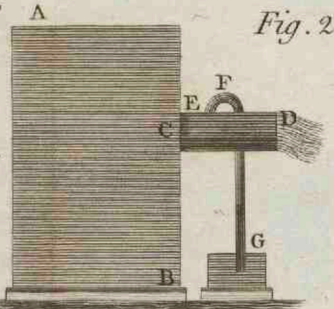

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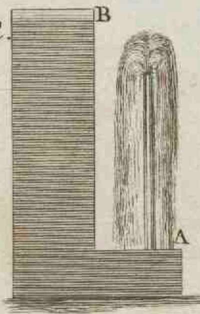

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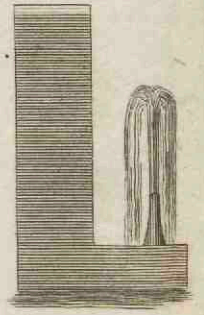

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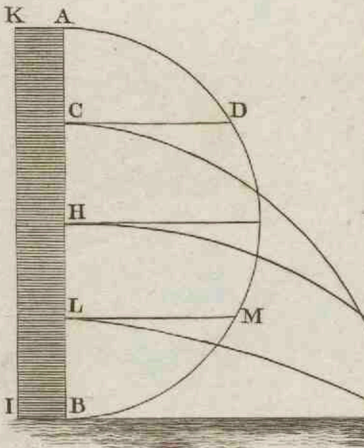

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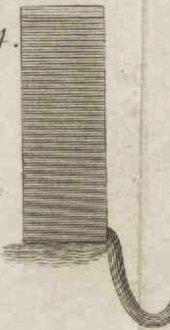

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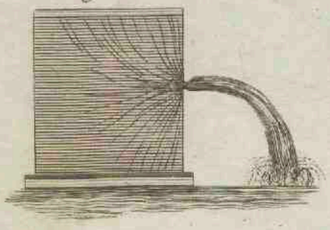

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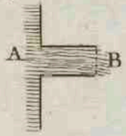

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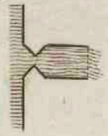

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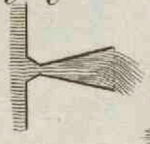

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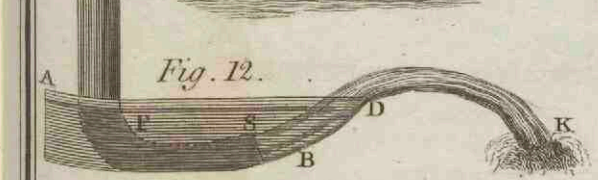

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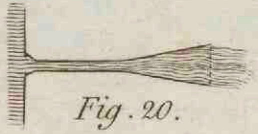

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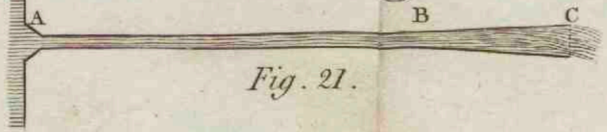

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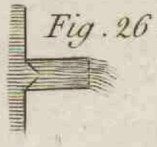

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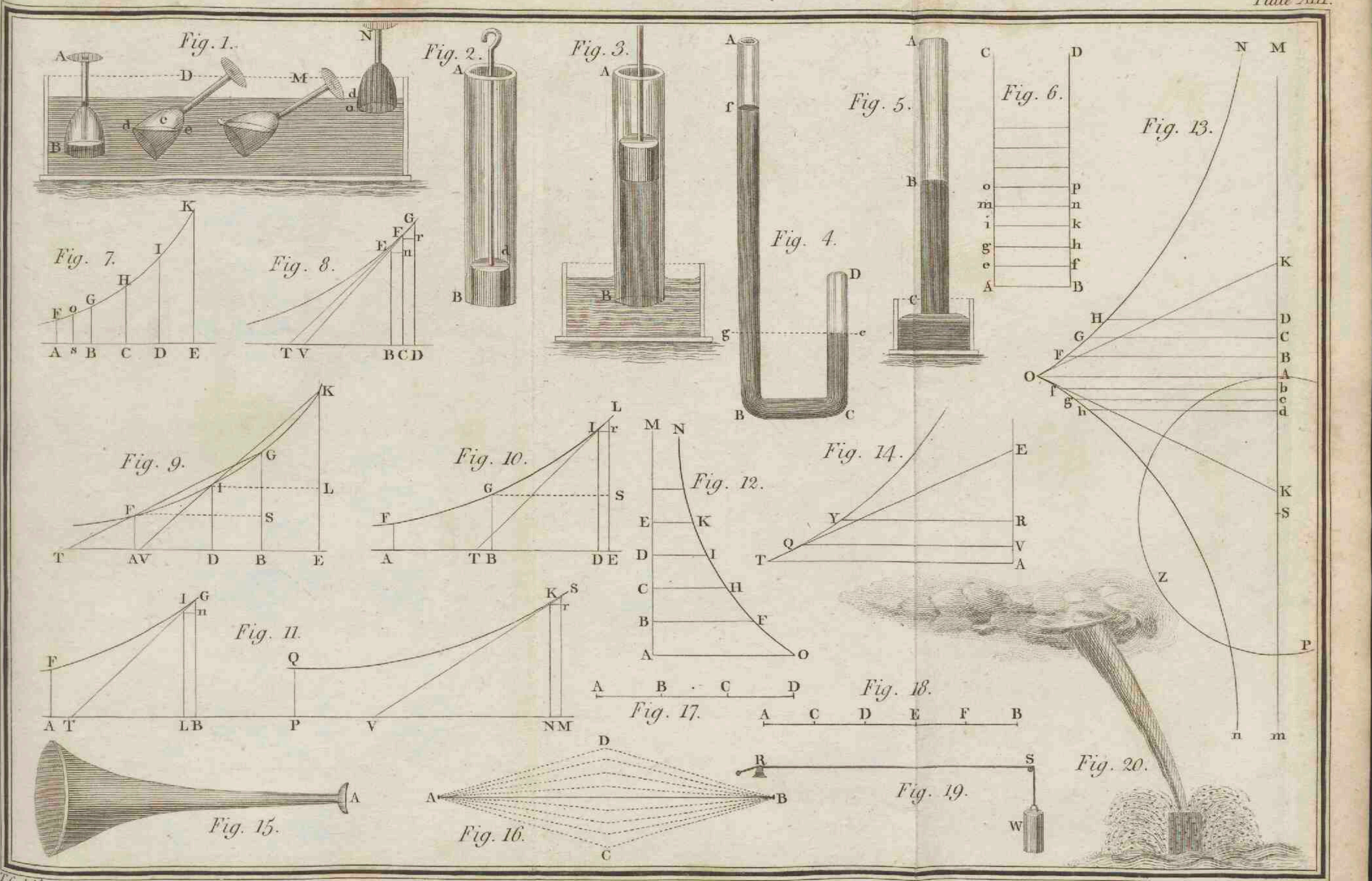
Plate XIII.



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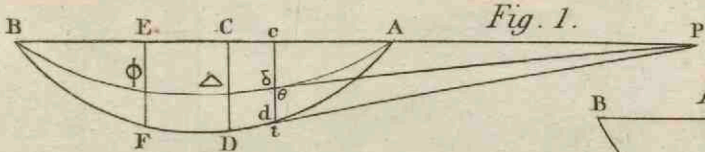

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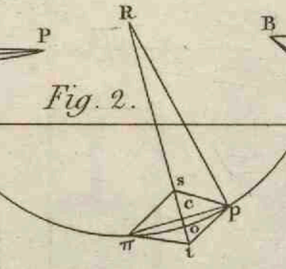
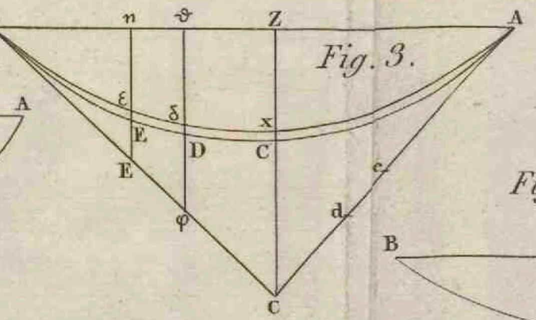


Fig. 2.



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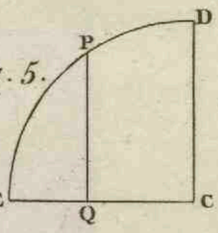

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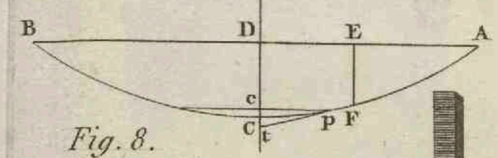

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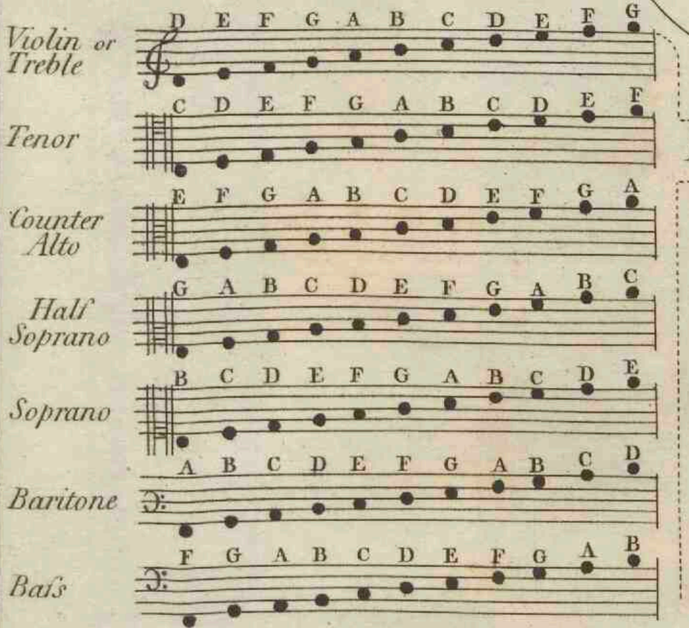
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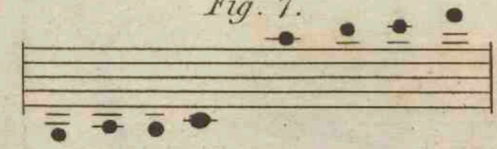

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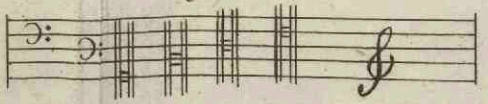

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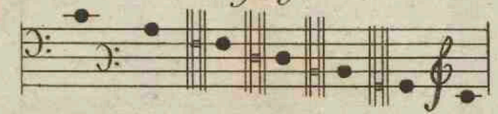
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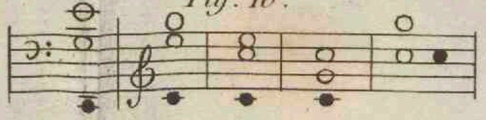
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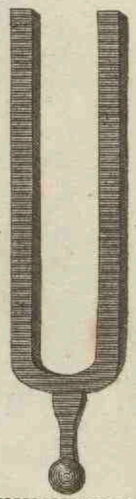
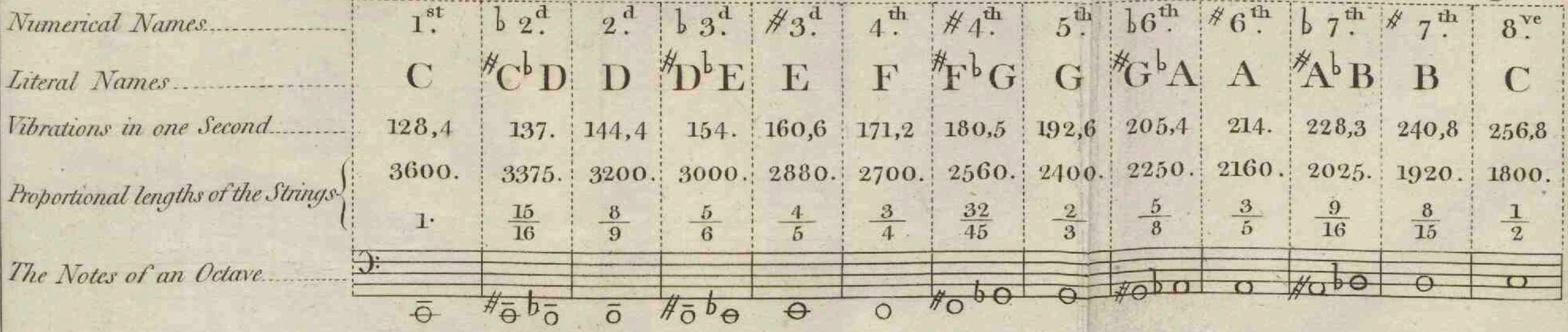


Fig. 11.

Fig. 12.



Numerical Names	1st.	♭ 2d.	2d.	♭ 3d.	♯3d.	4th.	♯4th.	5th.	♭6th.	♯6th.	♭ 7th.	♯ 7th.	8ve.
Literal Names	C	♯C♭D	D	♯D♭E	E	F	♯F♭G	G	♯G♭A	A	♯A♭B	B	C
Vibrations in one Second	128,4	137.	144,4	154.	160,6	171,2	180,5	192,6	205,4	214.	228,3	240,8	256,8
Proportional lengths of the Strings	3600.	3375.	3200.	3000.	2880.	2700.	2560.	2400.	2250.	2160.	2025.	1920.	1800.
	1·	$\frac{15}{16}$	$\frac{8}{9}$	$\frac{5}{6}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{32}{45}$	$\frac{2}{3}$	$\frac{5}{8}$	$\frac{3}{5}$	$\frac{9}{16}$	$\frac{8}{15}$	$\frac{1}{2}$
The Notes of an Octave													

T.C. del.t

J.s Basire sc.

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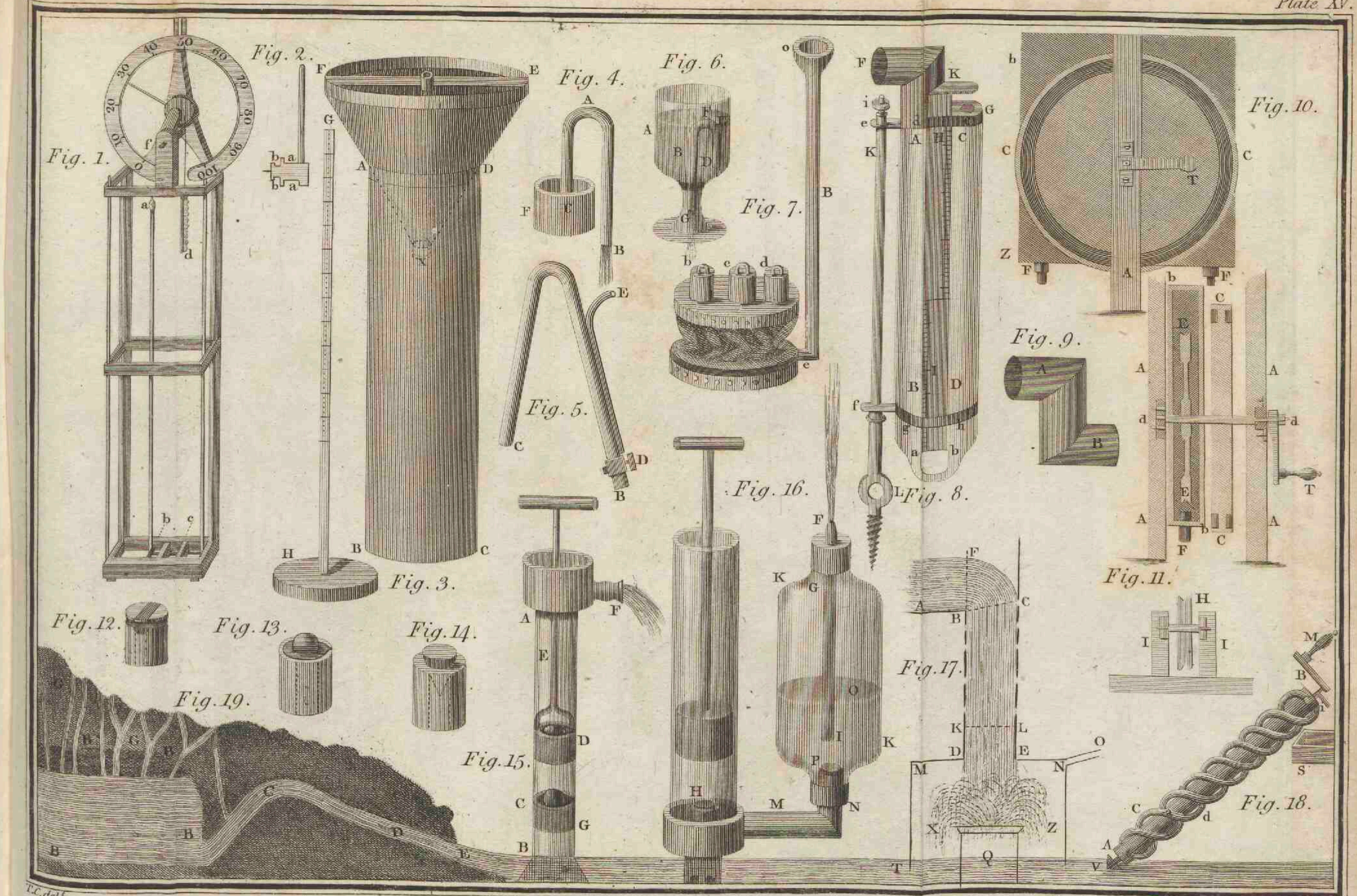
Plate XV.



T.C. del.

J. Basire sc.

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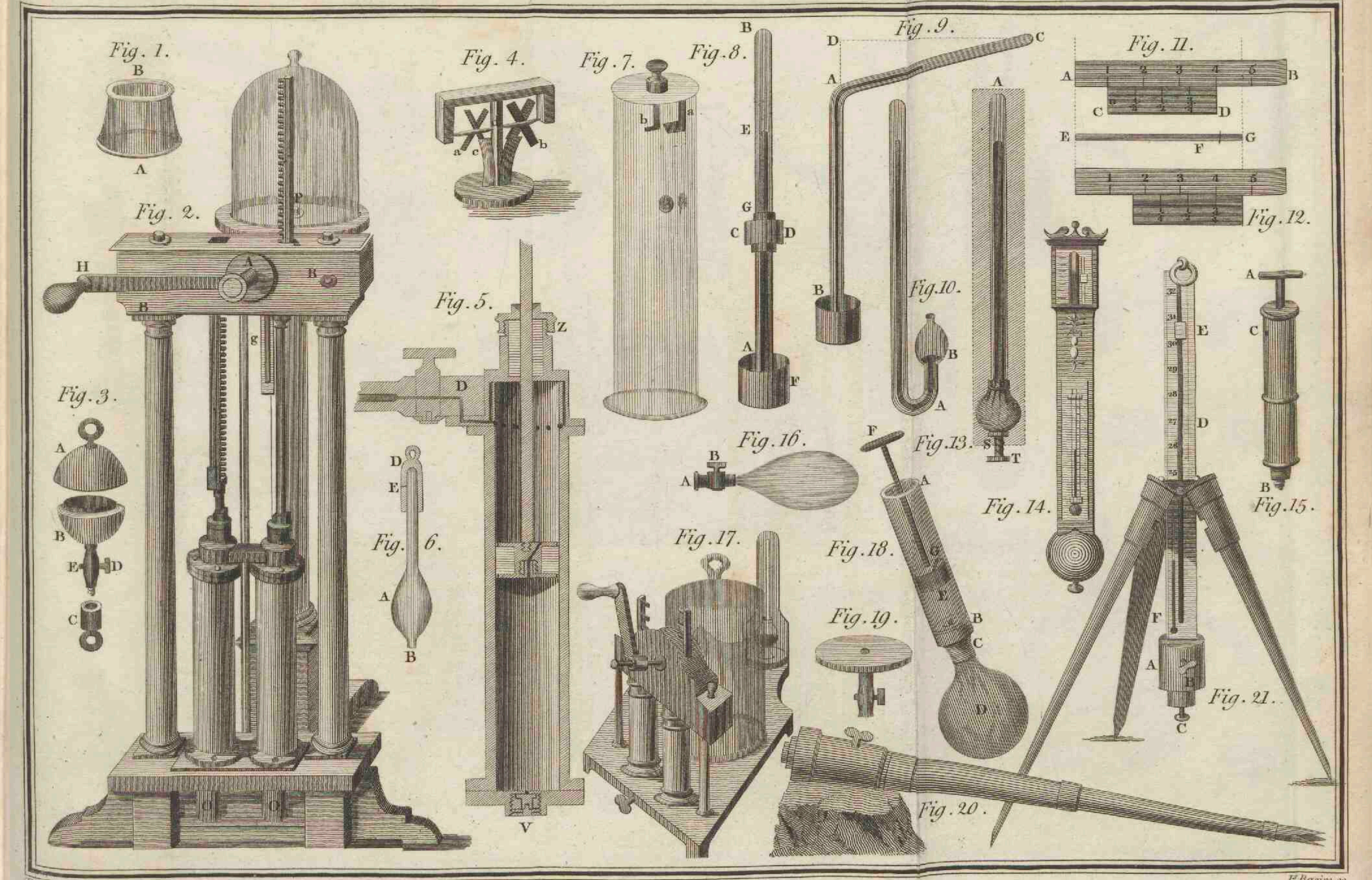
Plate XVI.



T.C. del.t

J.s Basire sc.

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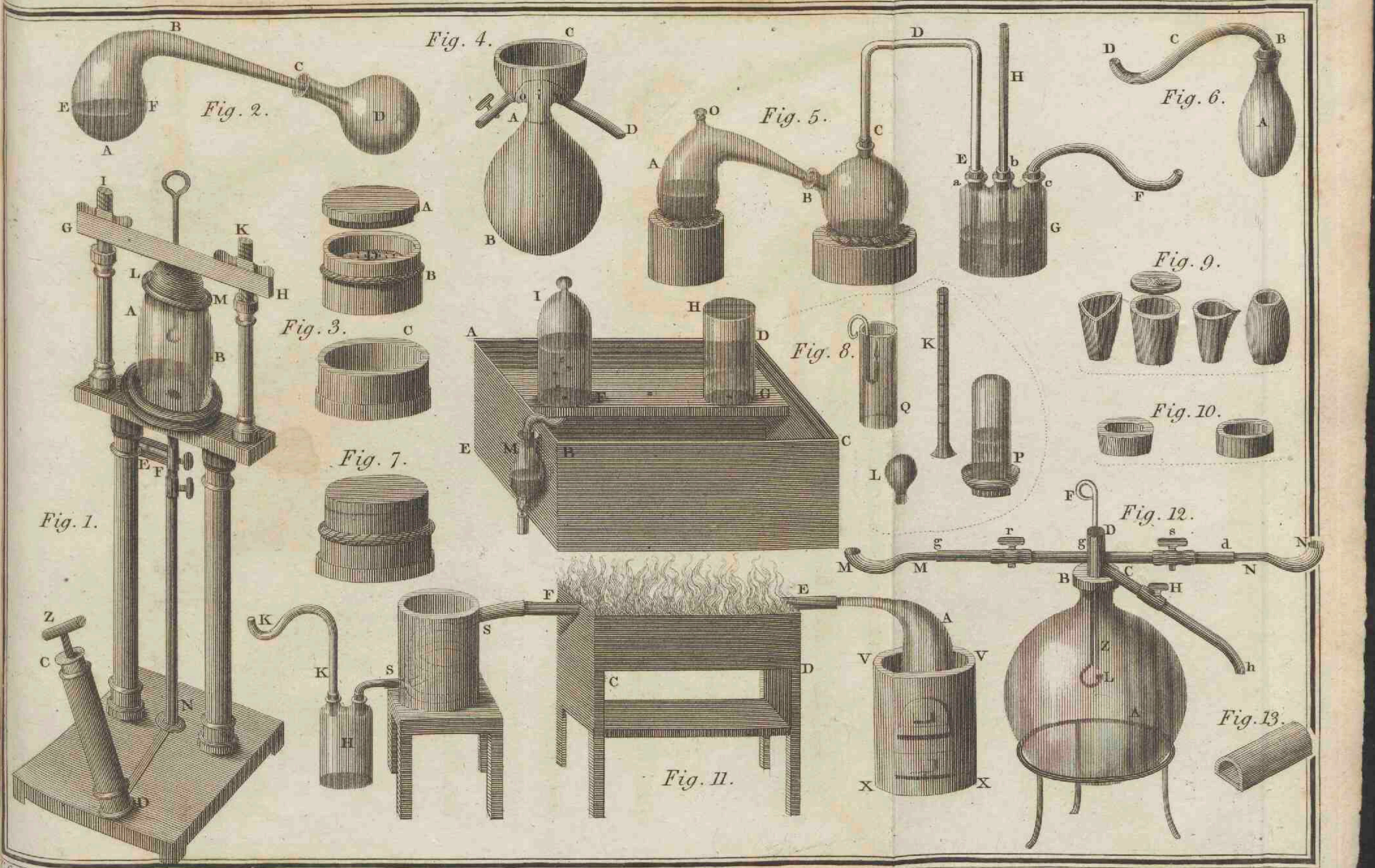
Plate XVII.



C. delt

Js. Basire sc.

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