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Ο ΒΙΟϹ
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ΔΕ
ΜΑΚΡΗ

To my friend Dr. W. A. Daley with all good wishes for a successful career
Robert [illegible]

THE

ECONOMY OF NATURE

EXPLAINED AND ILLUSTRATED

ON THE

PRINCIPLES

OF

MODERN PHILOSOPHY.

BY

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IN THREE VOLUMES.

WITH FORTY-SIX PLATES.

VOL. I.

LONDON:

PRINTED FOR J. JOHNSON, Nº 72, ST. PAUL'S CHURCH YARD.

1796.

PREFACE.

THE want of a popular treatiſe of philoſophy, one which might ſerve as a proper introduction to natural hiſtory; to explain to general readers the great principles and operations of nature; to give, in a united view, the diſcoveries of the moderns on theſe important ſubjects, firſt ſuggeſted to me the preſent undertaking.

It is now many years ſince I projected this work, and I intended to have termed it, "The Philoſophy of Natural Hiſtory."—In that title I have been anticipated; but my plan, though long ſince announced very amply to the public, has not yet been anticipated, and the work is ſtill as much wanted as when I firſt conceived the intention of undertaking it.

To diſtinguiſh certainty from conjecture is the moſt difficult taſk of the ſcholar; a taſk which few find leiſure, fortitude, or attention to complete. In the preſent imperfect ſtate of knowledge, when I ſay *certainty*, I perhaps would confine the reſearches of human wiſdom within too narrow limits; and *probability* may be the more ſuitable expreſſion, which muſt, indeed, comprehend no inconſiderable portion of our diſcoveries in nature. To ſeparate, therefore, the probable from the fanciful, was my firſt object; and, if I was not apprehenſive of being thought too aſſuming, I would add, the *uſeful* from the ſpeculative. I have obſerved, that in all ſciences the principal difficulties ariſe from certain controverted and diſputable points, which are of little importance in themſelves, and which, as they are not eſtabliſhed upon competent evidence, are not eaſy to be comprehended.

To expect much of novelty in the following pages, would be to expect falſehood and abſurdity. One man, even with the unparalleled powers of a Newton, is able in the courſe of his life to make but few diſcoveries of importance; and after the toil of centuries, it would be extraordinary if much of what is really true was left to be diſcovered. If I have ſucceeded in placing in a clear and perſpicuous light the obſervations of others; if I have collected, and arranged in a lucid order, the leading truths in the different branches of philoſophy, I have performed a great taſk; but this I dare not flatter myſelf I have been able to accompliſh.

Imperfect, however, as the work muſt, I am confident, ſtill appear—it is yet the labour of ſome of the moſt valuable years of my life, with the aſſiſtance of ſome learned and excellent friends, whoſe kindneſs in theſe inſtances I ſhall have preſently to acknowledge more at large. Let thoſe who may be diſpoſed to complain that more has not been done, only reflect on the difficulty of what has been effected, and I flatter myſelf they will receive with candour an attempt, in which not to have ſucceeded would ſcarcely reflect diſgrace on talents ſuperior to mine.

I have endeavoured to lay open the whole book of nature to my readers. I commence with the firſt principles of philoſophy, the laws of matter and motion, with an enumeration of the moſt ſimple or elementary ſubſtances. I proceed from theſe to explain the nature and phenomena of that moſt active and ſubtle of elements, heat or fire, which is ſo intimately connected with all other ſubſtances. The theory of light and colours, ſo immediately dependant on the preceding ſubject, ſucceeds; and this is followed by a ſhort treatiſe of electricity. The different ſpecies of airs, and the atmoſpherical phenomena, are next treated of; theſe are ſucceeded by a deſcription of the earth and mineral kingdom, and the moſt remarkable phenomena connected with them, ſuch as volcanoes, earthquakes, &c. The nature and compoſition of water, with a ſhort account of mineral waters, and of the general properties of that fluid, occupy the next department of the work.

From

From thefe fubjects, I have proceeded to what is called the vegetable kingdom, including what is known on the nature and theory of vegetation. The animal economy fucceeds; and that as little as poffible might be wanting to complete the courfe of elementary knowledge, I have concluded by a fketch of the human mind. This latter part will connect properly with my Effays Hiftorical and Moral, publifhed fome years ago, and which contain the great outlines of my fentiments on moral and political philofophy.

As it was my defire to make this treatife as plain and clear as poffible to unlearned perfons, I have to apologize to my more fcientific readers for the occafional repetition of the fame principles and obfervations. Having been, in fome meafure, all my life engaged in the bufinefs of education, I have feen the neceffity of frequently recalling the attention of young perfons to principles already proved and eftablifhed, in order to enable them to underftand what is to be taught. In giving the hiſtory of different ſciences alſo, many facts and obſervations are naturally anticipated; and yet it becomes abſolutely neceſſary to confirm, illuſtrate, and apply theſe in a more extenſive manner, in treating of the ſciences at large.

I have omitted aſtronomy, becauſe I thought it right to confine my view of nature to our own world; and becauſe, while Derham's, Ferguſon's, and Bonnycaſtle's writings on that ſubject are extant, there is no want of a good and popular treatiſe. I have entered but little into mechanics, becauſe the conſtruction of machines is rather the work of art than of nature *; and where I have been obliged, in illuſtration of any principle, to deſcribe certain well-known machines or engines, I have, for that reaſon, frequently extracted the deſcription from ſome popular writer.

* The Reader will find all theſe topics, and indeed almoſt every thing relating to what is termed experimental philoſophy, excellently explained in Mr. Nicholſon's very uſeful and accurate Introduction to Natural Philoſophy.

If

If it is aſked, for whoſe uſe this work is deſigned? I anſwer, for all whoſe curioſity would lead them to take a general ſurvey of nature—for all, in particular, who wiſh to underſtand the elements and principles of natural hiſtory. I conceive alſo, that it will not be unuſeful to the younger ſtudents of medicine, as it is intended as an eaſy introduction to general ſcience; and as it comprehends all the firſt principles of chemiſtry and phyſiology. With the more enlightened claſs of female readers, I cannot but flatter myſelf that the work will be favourably received, as I really had their entertainment and information principally in view in compiling it; and they may depend upon it, that there is not a ſingle expreſſion in the whole that can reaſonably offend the moſt delicate and modeſt ear.

To ſome perſons, who, I muſt obſerve, have rather more zeal than knowledge, ſtudies ſuch as theſe may appear rather inconſiſtent with the clerical profeſſion and the ſcience of theology, a ſcience extenſive enough, I confeſs, fefs, to occupy the life of a man. I might reply by a fimple fact, that *I never yet have been enabled to gain, by the exercife of my profeffion, a livelihood for myfelf and family*; and it muft appear a hard cafe to confine the whole attention of any man to what will not furnifh him with the neceffaries of life; yet the great bulk of my previous publications (without excepting my Effays) have been in the direct line of my profeffion. I do not, however, reft my apology upon this argument, but I muft fay, that in publifhing the prefent work, I believe I am not lefs effentially ferving the caufe of religion, than if I had been employed in compiling a treatife of divinity. Next to the ftudy of the fcriptures, there is none which feems to lead the human mind fo directly to a knowledge of its Creator, as the ftudy of nature. In an age therefore when atheifm is publicly profeffed by fome, and privately but feduloufly diffeminated by others, I cannot but hope that a work like the prefent may have fome good effects; and though I have not, like an eminent philofopher of the clerical profeffion, termed it a phyfico-theology, the reader will perceive

perceive that this application of the hiſtory of nature has not been forgotten.

As I have no great cauſe to be intoxicated with my ſucceſs in life; and as I am verging upon that period when man has little to hope or fear in this world, I feel that it is no affectation to ſay, I am not extremely ſolicitous for literary fame; yet I will not diſſemble, that I would, if poſſible, deprecate on the preſent occaſion the ſeverity of criticiſm, both becauſe I would wiſh my publiſher to be indemnified, ſince my very limited means will not admit of publiſhing on my own account; and becauſe I would not wiſh thoſe friends who have generouſly afforded me aſſiſtance in the preſent work, to ſuffer any uneaſineſs from the harſhneſs of cenſure, or by my ſolicitations to have been drawn into a diſagreeable predicament.

It remains to do juſtice to theſe friends. "To render honour to whom honour is due; praiſe to whom praiſe," is the part not only of the chriſtian, but of every honeſt man. In the optical part of this work I have been materially

terially aſſiſted by a gentleman of known and diſtinguiſhed abilities, who taught publicly for a ſeries of years the ſeveral branches of natural philoſophy, but who will not permit me to make my acknowledgments in a more particular manner. For, I may ſay, the whole of the animal economy, I am indebted to my valuable and ſcientific friend Dr. Belcher, of Maidſtone, as well as for moſt eſſential aſ-ſiſtance in the mineralogy and the vegetable ſyſtem, and for reviſing and correcting ſeveral other parts. It would be impoſſible to ſpecify the authors from whom I have extracted my materials: I have inſerted references as frequently as I could with convenience. In ſome inſtances the reference was neglected in the copying of my original notes; and in ſome, the facts were commonly known, and diffuſed through a multitude of authors.

Chapel Street, Bloomſbury,
June 30th, 1796.

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BOOK I.

OF THE GENERAL PROPERTIES OF MATTER.

CHAP. I.

OF MATTER IN GENERAL.

Explanation of Terms.—Whether all Matter is radically the ſame.—General Properties of Matter.—Quantity of Matter in the Univerſe.

THE word MATTER (*materia,* which ſome lexicographers have derived from *mater,* a mother) denotes, in its primitive ſenſe, that unexplained ſomething, from which all other things are formed.

The term *body* is ſometimes confounded with that of matter; but they are eſſentially different: Body (bodiᵹe) is of Saxon origin. It is explained by the Latin words *ſtatura, pectus, truncus*; and ſignified the *perſon* or *form* of a *man,* or other *creature:* whence it is plain that it ought to be confined to expreſs a ſubſtance poſſeſſing form or figure.

Subſtance, both in its etymology and application, approaches nearer to the meaning of the former of theſe terms. It is well known to be compounded from the Latin prepoſition *ſub* (under), and the verb *ſtare* (to ſtand.) It conſequently implies that which *ſupports* or *ſtands under* the different forms and appearances which are preſented to our ſenſes. It is ſtill, however, uſed in a diſtinct and more limited ſenſe than matter. It is generally indeed uſed with the definite article, to ſignify a diſtinct or definite portion of matter; whereas *matter* in the abſtract implies a more confuſed and general idea of ſolidity and extenſion, with little or no regard to figure, proportion, or quantity.

Theſe words are of ſuch common and frequent uſe in philoſophy, that it appeared neceſſary to have a competent notion of their force and meaning, particularly in a chapter which profeſſes to treat of the firſt of them: and I have generally found etymology a ſafer and eaſier mode of communicating knowledge than definition.

That the whole matter, of which this univerſe of things is compoſed, is eſſentially the ſame, and that the apparent differences which ſubſiſt in different bodies depend altogether on the particular diſtribution or diſpoſition of the component particles, is an opinion which has been entertained by ſome philoſophers of the higheſt reputation. The wonderful apparent tranſmutations which take place in the different proceſſes and operations of nature do, it muſt be confeſſed, at firſt ſight countenance this hypotheſis. A plant will vegetate and become a ſolid ſubſtance in the pureſt water *. The genera-

* See the experiments of Mr. Boyle and Van Helmont, Book VIII. c. iii.

tion

tion of ftones in the earth, the various phenomena of petrifactions, and a multitude of other facts, contribute greatly, on a fair confideration, to diminifh the abfurdity of the alchemifts, who feem chiefly to have refted on this hypothefis (*viz.* that all matter was intrinfically the fame) their hopes of converting the bafeft materials by the efforts of art into the moft fplendid and valuable of fubftances.

Mr. Boyle diftilled the fame water about two hundred times, and at the end of each diftillation found a frefh depofit of earth. M. Margraff repeated the experiment with ftill greater caution. By means of two glafs globes, which communicated with each other, he preferved the water while in the ftate of vapour from all contact with the air; and on repeated diftillation, a quantity of earth of the calcareous * kind was depofited at the conclufion of each procefs.

The extreme rarity and minutenefs of the particles into which different fubftances may be refolved, imparts a ftill greater degree of probability to this hypothefis; and in general, the more any body can be divided, the fimpler it appears in its component parts.

We muft however be cautious of admitting opinions, which are not fanctioned by the direct teft of experiment; and however plaufible the opinion, the accurate obfervations of modern philofophy have fuggefted fome objections to the homogeneity of mat-

* Earth of lime.

ter, which without further discoveries it will not be easy to silence.

Whatever phenomena may appear to indicate a transmutation of bodies, or a change of one substance into another, we have the utmost reason, by the latest and best experiments, to believe them merely the effect of different combinations. Thus the conversion of water and air into a solid substance, such as the body of a plant, is merely an apparent conversion, for that solid substance may, by an artificial process, be resolved again into water and air, without any real change in the principles or elementary particles of which those fluids are composed: and the formation of stones, and the phenomena of petrifactions, are accounted for upon much easier principles than that of transmutation. On the other hand, the utmost efforts of chemistry have never been able to proceed farther in the analysis of bodies than to reduce them to a few principles, which appear essentially different from each other, and which have never yet been brought to a more simple form. Thus the matter of fire, or light, appears totally different from that of all other bodies; thus the acid and alkaline principles can never be brought to exhibit the same properties; nor can even the different species of earths be converted into the substance of each other.

If hypothetical reasoning was to be admitted on this occasion, it would probably appear more agreeable to the analogy of nature, to suppose that different substances are formed from the different

rent combinations of a few fimple principles in different proportions, than that the very oppofite qualities of fome of the rareft and moft fubtile fluids, fhould depend wholly on the different form or modification of the extremely minute particles which enter into their compofition.

It is proper however to obferve, that on this fubject there has hitherto appeared no decifive experimental proof on either fide. The imperfection of all human efforts, and perhaps of the human faculties themfelves, have hitherto confined our inveftigations to the properties of a few fubftances, the fimpleft which chemical analyfis has been able to obtain, and which for that reafon are denominated ELEMENTS.

There are fome properties which are accounted common to all matter, and which from their importance will require to be feparately treated of: thefe are SOLIDITY, EXTENSION, and DIVISIBILITY, ATTRACTION, MOTION, and REST.

The quantity of matter which is contained in the whole univerfe may probably be much lefs than common obfervation would lead us to fuppofe. The fublime mathematics of Newton dictated the aftonifhing propofition: "that the whole globe of 'earth, nay that all the known bodies in the uni'verfe may, as far as we know, be compounded of 'no greater a portion of folid matter than might be 'reduced into a globe of one inch only in diameter, 'and even lefs*!'

* Pemberton's View of Sir I. Newton's Philofophy, 356.

Chap. II.

OF ELEMENTS *.

Opinions of the Ancients.—New Arrangement.—Enumeration of simple Substances, according to the new Philosophy.—Aërial Substances.—Earths.—Metals.

WHEN we take a general survey of nature, we find that notwithstanding the apparent variety of creatures, with which the universe abounds, every natural body which has hitherto come within the limits of our inspection may be reduced into a few distinct kinds of matter: and though we probably have not as yet discovered the ultimate and most subtile principles of which bodies are compounded; yet we appear to be justified in calling the most simple substances which we have been able to discover as entering into the composition of bodies by the name of Elements.

Aristotle, and after him most of the ancients, admitted four different elements, *fire*, *air*, *earth*, and *water*. It is evident, in the first place, that in this enumeration the salts are omitted, the existence of which can no more be doubted than that of any of the others. Secondly, it was found necessary in

* From Cleo, or Eleo, to create.

the progreſs of ſcience, not only to admit a *ſaline*, but a ſulphureous or *inflammable* principle. I might add, that we are warranted by no experiments, which have as yet been made public, in ſuppoſing that there exiſts but one ſimple ſpecies of earth; and later experiments ſeem to determine that water as well as air is a compound ſubſtance *.

It is, therefore, neceſſary to adopt a new arrangement, though it is more than probable that future diſcoveries may render it in ſome meaſure nugatory. Future diſcoveries may perhaps demonſtrate that many, if not moſt, of the following ſubſtances will yet admit of ſubdiviſions; or they may demonſtrate that the conſtituent principles of bodies are ſtill fewer. They may demonſtrate that all earths have originally the ſame baſis, and are only altered by different combinations with vital air or other ſubſtances; the alkaline ſalts may be in reality a ſpecies of earth, which alſo derives its diſtinguiſhing qualities from a union with ſome ſubtile matter in a certain proportion. Theſe, however, are points on which we have at preſent obtained no experimental evidence, and which for that reaſon we are not authorized to affirm.

The moſt ſimple ſubſtances hitherto diſcovered may be reſolved into,

* I ſhall not perplex the reader with the exploded viſions of chemiſts during the laſt two centuries, with their *phlegm* or watry principle, their *mercury* or active and ſpiritous principle, their *caput mortuum*, their *ſpiritus rector*, and a quantity of uſeleſs and almoſt unintelligible jargon.

 1. Fire,

1. Fire, heat, or caloric; including light and the electric fluid.

2. The baſe of pure, vital, or dephlogiſticated air, the oxygen of the French chemiſts.

3. Hydrogen, or the baſe of inflammable air.

4. Azote, or the baſe of nitrous acid.

5. Sulphur, the baſe of vitriolic acid.

6. Phoſphorus, the baſe of phoſphoric acid.

7. Coal * or Carbon, the baſe of fixable air.

8. The unknown radicals of the muriatic, fluoric, and boracic acids.

9. The fixed alkalis.

10. Earths.

11. Metals.

The different earths which are as yet known to philoſophers are,

1. Calcareous, or earth of lime.
2. Silicious, or earth of flints.
3. Argillaceous, or clay.
4. Magneſia.
5. Barytes, or ponderous earth.

The metals again are ſubdivided into,

1. Arſenic.
2. Molibdena, or black lead.
3. Nickel.
4. Cobalt.

* More properly charcoal, for our common pit-coal is a heterogeneous maſs, containing much foreign matter, as may be ſeen book VI. c. 37. I have however employed the generic term *coal,* becauſe charcoal, though much the pureſt of theſe bodies, is in this country conſidered not as a natural but a factitious ſubſtance.

5. Biſmuth,

5. Biſmuth.
6. Antimony.
7. Zinc.
8. Tungſtein.
9. Manganeſe.
10. Tin.
11. Lead.
12. Iron.
13. Copper.
14. Mercury.
15. Silver.
16. Gold.
17. Platina.

Each of theſe may at preſent be conſidered as a diſtinct elementary ſubſtance, ſince they are found to be unchangeable or unconvertible into other ſubſtances, though they may be, and generally are, combined with others. This fact, was it not for the advantage of claſſification, and for ſome doubts which yet remain on the minds of philoſophers concerning the eſſential difference of the earths, would oblige us to admit in nature, inſtead of eleven, at leaſt thirty-three diſtinct, ſimple, and elementary ſubſtances.

Chap. III.

OF THE EXTENSION, SOLIDITY, AND DIVISIBILITY OF MATTER.

Extenſion the only Quality eſſential to Matter.—Solidity, what.—Infinite Diviſibility.—Animalculæ imperceptible to our Senſes.—Extreme Rarity of Light.—Newtonian Paradox.

EXTENSION is a property ſo obviouſly eſſential to whatever occupies ſpace, that it is accounted the firſt and moſt indiſpenſable attribute common to all matter. It is indeed the only property which we can poſitively ſay is eſſential to matter, ſince all the others that have been ſpecified are to be underſtood with ſome limitation, and do not appear to be common to all bodies whatever.

We have no idea of *ſolidity*, but that which is furniſhed by the reſiſtance which we find in a body to the entrance of any other body into the place it occupies till it has left it *. This property of matter therefore neceſſarily includes neither impenetrability nor hardneſs; the amazing poroſity of bodies militates againſt the one idea, and the almoſt infinite diviſibility of matter againſt the other.

* See Mr. Locke's Eſſ. on Hum. Under. B. ii. c. 4.

Indeed

Indeed nothing can be more inconſiſtent than to ſpeak of the abſolute ſolidity and impenetrability of the ultimate particles of matter, and afterwards to enlarge upon its infinite diviſibility; both of theſe are facts which are totally undetermined by experiment or obſervation; and when we ſpeak of the actual properties of matter, we ought, I apprehend, to confine ourſelves to the teſtimony of our ſenſes.

How improperly the idea of impenetrability is applied to any bodies which we are acquainted with, is evident from the aſtoniſhing eaſe and velocity with which the electric fluid paſſes through the denſeſt bodies, and from the continual paſſage of light through a variety of ſubſtances, which afford to our ſenſes the moſt perfect idea of ſolidity, through glaſs, and diamond and other precious ſtones: the focus of a burning mirror, which augments the denſity of the ſun's rays upwards of three thouſand times, may be received in glaſs or water without producing any effect: even ſubſtances of ſenſible bulk and ſolidity can exiſt within the pores of other bodies. Thus quickſilver exiſts within the pores of either ſilver or gold; in fact a mixture of mercury and ſilver is conſiderably heavier than an equal bulk of either of thoſe metals. The common bell-metal is a mixture of copper and tin; and though the latter is ſpecifically lighter than the former, yet bell-metal is conſiderably heavier than an equal bulk of copper itſelf; which is an evident proof that the particles of the one actually enter into, and are depofited in the pores of the other. What is perhaps ftill more extraordinary, a definite quantity of falt may be added to a quantity of water without increafing its bulk, nay a fmall quantity of falt added to water will even caufe it to contract.

The *divifibility* of matter is alfo received with limitation by thofe who contend for the exiftence of atoms or firft principles of bodies; fince, if their exiftence is admitted, there muft neceffarily be fome parts or portions of matter indivifible, and confequently it cannot be admitted as a property inherent in all matter.

The human faculties are loft in the purfuit, and the human underftanding in the contemplation of the actual divifibility of matter. The fmalleft animalcula which is brought within our notice by the microfcope poffeffes organized parts, blood and other fluids neceffary for the fupport of life, yet how infinitely removed are thefe from our infpection! Some idea, however, may be formed of the aftonifhing power of matter in this refpect, from inftances which are furnifhed by all the moft common experiments of philofophy. A pound of even fo grofs a fubftance as cotton, may be fpun into a thread upwards of one hundred miles in length *; and Mr. Boyle fpeaks of a thread of filk 300 yards in length, which weighed no more than three grains and a half. This, however, is ftill furpaffed by the amazing ductility of gold; fixteen ounces of which would

* Repofitory, vol. ii. p. 52.

completely

completely gild a wire ſufficient to circumſcribe the whole globe of the earth, though that quantity of the metal might be contained in a cube of not more than an inch and a quarter in diameter. The metallic particles are yet more minutely divided in the acid ſolutions. A ſmall piece of the ſalt of ſilver, which is ſilver already divided and united to the nitrous acid, not larger than a common pin's head, will tinge a quart of water of a milky colour; and even the hundredth part of a grain of copper will impart a ſenſible blue to a pint of the ſame fluid.

It is well known that camphor, muſk, and other odoriferous ſubſtances will emit particles that ſhall powerfully affect the organs of ſcent, and ſhall communicate their peculiar fragrance to the ſurrounding air for a conſiderable ſpace of time, without any perceptible decreaſe of weight. The extreme rarity of the elaſtic fluids is a further proof of the diviſibility of matter. Gunpowder, when exploded, expands to 244 times its bulk when in a ſolid ſtate; and water in the ſtate of vapour occupies a ſpace 1800 times greater than in its natural fluid form*. A par-

* This fact may at any time be proved by an eaſy experiment. Take a common flaſk, and let it be exactly weighed; fill it with water, and then let it be weighed again—after the water is emptied, there will neceſſarily be a little moiſture adhering to the ſides; put the flaſk before a fire to evaporate the moiſture, and when the whole of the water diſappears, cloſe the flaſk, and weigh it again, and you will then have the weight, and conſequently the bulk of vapour, compared with that of water.

ticle

ticle of light has been estimated, on apparently a well conducted calculation, at $\frac{1}{30,831,230,128,000}$ of a grain *.

We shall indeed cease to wonder at such a calculation, when we consider that by means of this fluid the unparalleled wonders of the microscopic world are made cognizable to our senses. The scarf-skin of the human body is said to be composed of minute scales resembling those of fishes, *two hundred* of which may be covered by a grain of sand; under these scales there lie concealed a number of pores, or excretory ducts, through which the perspirable matter is supposed to issue, and *one hundred and twenty* of such pores in a direct line extend to only one tenth of an inch. If such therefore is the organization of the human body, what shall we think of the organized parts of those animals which are themselves *one thousand times* too small to affect the human eye without the aid of art? Animalculæ, however, have been discovered nearly one hundred times smaller than these, many thousands of which may dance upon the point of a fine needle: indeed Lewenhoek calculates that one thousand million of such animalculæ as are discovered in common water would not equal in magnitude a grain of common sand. When therefore we consider that such animalculæ are possessed of organized parts; a heart, stomach, bowels, muscles, tendons, nerves, glands, &c. we seem to

* Boudoin on Light. Memoirs of the American Acad. Vol. I. p. 198.

approach

approach in idea the infinite divifibility of matter *.

It is, on the other hand, next to an abfolute certainty, that the particles of the hardeft and moft compact bodies are not in actual contact with each other, fince all fuch bodies are known to contract with cold; which could not be the cafe, if their parts were already as clofe as they could be to each other.

It would be foreign to the defign of this work to enter into thofe calculations and demonftrations by which mathematicians have attempted to prove how matter may be divided to infinity. Let it fuffice to fay, that on the principles which have been advanced in the courfe of this chapter, the fagacity of Newton has demonftrated, that the leaft portion of matter may be wrought into a body of any affigned dimenfions, how great foever, and yet the pores of that body be none of them greater than any the fmalleft magnitude propofed at pleafure; notwithftanding that the parts of the body fhall fo approximate, that the body itfelf fhall be hard and folid. His manner of demonftration is this—fuppofe the body to be compounded of particles of fuch figures, that when laid together the pores found between them fhall be equal in fize to the particles themfelves; how this may be effected, and yet the body

* If the reader wifhes to fatisfy himfelf concerning the nature and animal functions of a variety of thefe wonderful exiftences, I muft refer him to my late much valued friend Mr. Adams's excellent Treatife on the Microfcope.

remain

remain solid, is not difficult to understand; and the pores of such a body may be made of any proposed degree of smallness. But the solid matter of a body so framed will take up only half the space occupied by the body; and if each constituent particle is composed of other smaller particles, according to the same rule the solid parts of such a body will be but a fourth part of its bulk; if every one of these lesser particles again are compounded in the same manner, the solid parts of the whole body will be but one eighth of its bulk; and thus by continuing the composition, the solid parts of the body may be made to bear as small a proportion to the magnitude of the whole body, as shall be desired, notwithstanding the body shall, by the contiguity of its parts, be capable of being in any degree solid *.—When these facts are considered, the hypothesis of the same incomparable philosopher, concerning the small quantity of solid matter contained in the universe, as noticed in a preceding chapter, appears less incredible.

* Pemberton's View, 355.

CHAP.

Chap. III.

OF ATTRACTION AND REPULSION.

Five Kinds of Attraction—Cohesion—Combination—Crystallization explained—Gravitation—Specific Gravity, what—Magnetic and electrical Attraction—Repulsion.

FIVE different kinds of attraction have been enumerated by modern philosophers. 1. The attraction of cohesion; 2. Of combination, or, as it is called by chemists, elective attraction; 3. Gravity; 4. The magnetic attraction; and, 5. The attraction of electricity. Whether the same principle acts in all these cases, or whether each of these effects depends upon a distinct cause, human sagacity has not been able to discover; nor is there any instance in which the principle of attraction seems to approach to the nature of a general law, except in that of gravity; and yet even this is not without an exception; since by every experiment that we have hitherto been able to make, there is no reason to believe that the element of fire, or heat, is subject to the common laws of gravitation. Unless, therefore, it could be proved that the principle of attraction is the same in all these cases that have been enumerated, we, perhaps, are scarcely correct in considering it as a general property of matter; and even ſuppoſing the cauſe to be the ſame, it may, after all, belong rather to ſome particular ſpecies of matter, which acts upon or impels all other bodies, than to matter in general.

I. The attraction of COHESION may be obſerved in almoſt all the moſt common operations of nature, and is exemplified by a variety of eaſy experiments. Two leaden balls, having each a ſmooth flat ſurface, if ſtrongly compreſſed together, will cohere almoſt as ſtrongly as if united by fuſion; and even two plates of glaſs, if the ſurfaces are even and dry, will require ſome force to ſeparate them *. By the ſame law of nature, the particles of even fluid bodies, in which the attraction is neceſſarily weaker than in ſolid ſubſtances, indicate a diſpoſition to unite.

The drops of dew that appear in the morning on the leaves of plants, aſſume a globular form, from the mutual attraction between the particles of water. Small portions of quickſilver, when brought near to each other, will run together, and aſſume the ſame globular appearance. Alſo, by the ſame law, a veſſel may be filled with water, mercury, or any other fluid, above the brim, and the fluid will be obſerved to riſe in a convex form.

To this principle we may very properly refer what is uſually termed *capillary* attraction. Thus, if a fluid is contained in a veſſel not full to the brim,

* See the ingenious Dr. Enfield's Inſtitutes of Natural Philoſophy.

it

it will always be attracted to the edges of the veſſel, and will aſſume a concave form. Thus, alſo, if two plates of glaſs, at a ſmall diſtance from each other, are immerſed perpendicularly in water, the fluid will riſe above its level between the two plates, and the height to which it riſes will bear a certain proportion to the diſtance of the plates. A capillary tube is a tube with an exceedingly ſmall bore, and by the ſame law which raiſes the water between the plates of glaſs, a fluid will riſe to a conſiderable heighth in one of theſe tubes. Both theſe experiments will anſwer equally well in the vacuum of an air pump, which proves that the effect is not owing to the preſſure of the air. In the ſame manner, alſo, by the ſame law, fluids will aſcend in the cavity of a ſponge, in the interſtices of linen cloth, or any porous body.

II. The attraction of COMBINATION, or chemical or elective attraction, is in many reſpects analogous to the attraction of coheſion. Like the latter, it ſeems to depend on the minute particles of bodies being brought nearly into contact with each other; and indeed ſo nearly alike are the effects of theſe two ſpecies of attraction, that if they are different in principle, it is difficult to ſay which is the moſt eſſential to the coheſion and ſolidity of bodies *.

Chemical

* The two ſpecies of attraction are well defined by Bergman: that which he calls the attraction of aggregation, I claſs under that of coheſion; that which he calls compoſition, I call combination. 'When an increaſe of maſs only takes place,

'the

Chemical attraction may probably be no other than the attraction of cohesion acting in a free and unresisting medium, since its only distinguishing characteristic is the disposition which bodies in solution indicate to unite with certain substances in preference to others. To make this clear by an experiment—If a quantity of silver is added to a quantity of aqua fortis, the cohesion of the particles of the silver will be destroyed, and they will unite forcibly with those of the aqua fortis. The fluid will, however, remain perfectly clear, the particles being so extremely minute, that the rays of light will suffer no interruption in passing through them. If, however, to this solution of silver a quantity of mercury or quicksilver is added, the aqua fortis will be attracted by the mercury, and the silver will be precipitated, or thrown to the bottom of the vessel in which the fluid is contained; if, again, copper is added, it will assume the place of the quicksilver; and if to this solution of copper a bright piece of

' the nature of the body remaining still the same, this effect is ' denominated the *attraction of aggregation*. But heterogeneous ' substances, when mixed together, and left to themselves to ' form combinations, are influenced by difference of quality ' rather than of quantity. This we call *attraction* of *composition*, ' and when it is exerted in forming a mere union of two or ' more substances, it receives the name of *attraction of solution* ' or *fusion*, according as it is effected either in the moist or dry ' way. When it takes place between three respectively, to the ' exclusion of one, it is said to be a *single elective attraction*, and ' when between two compounds, a *double*, &c." Berg. on Elec. Attr. i.

iron (for ruſt would exclude the acid from coming in contact with the metal) is introduced, the acid will immediately quit the copper and ſeize upon the iron, a quantity of which being diſſolved in the fluid, the copper will be depoſited in its place on the ſurface of the bar of iron *. The iron may afterwards

* 'This experiment explains to us, in a very ſatisfactory 'manner, the nature of that *tranſmutation of iron into copper,* which 'travellers have been ſo much ſurpriſed at. Agricola ſpeaks 'of waters in the neighbourhood of *Newſol,* in *Hungary,* which 'had the property of tranſmuting the iron which was put into 'them into copper †. In the year 1673, our countryman, Dr. 'Brown, viſited a famous copper mine at *Herrn-Grundt,* about 'ſeven Engliſh miles from *Newſol*; he informs us that he there 'ſaw two ſprings, called the old and new *ziment,* which turned 'iron into copper. The workmen ſhewed him a curious cup 'made of this tranſmuted iron; it was gilt with gold, had a rich 'piece of ſilver ore faſtened in the middle, and the following 'inſcription engraven on the outſide:

'*Eiſen ware ich, kupfer bin ich,*
'*Silver trag ich, gold bedeckt mich.*

'*Copper* I am, but *iron* was of old,
'Silver I carry, covered am with gold ‡.

'It was even at that time, he ſays, contended by ſome, that 'there was no real tranſmutation of iron into copper, but that 'the ziment water, containing vitriol of copper, and meeting 'with the iron, depoſited its copper; and it ſeems as if he would 'have acceded to this opinion, could he have told what became 'of the iron. It is now very well underſtood what becomes of 'the iron; it is taken up by the water, and remains ſuſpended 'in it, in the place of the copper; ſo that this tranſmutation is

† Agric. Foſ. L. ix. p. 347.
‡ Brown's Travels, ed. 1687. p. 69.

afterwards be difplaced by the addition of an alkali. This fpecies of attraction is called combination, becaufe the particles of two bodies by thofe means become fo intimately united or combined, that they cannot be feparated but by the addition of a third body, which has a greater attraction for one of the component bodies than they have for one another, and it is called elective attraction and affinity, from the fuperior tendency in fubftances to unite with certain bodies in preference of others. In all cafes of elective attraction it is neceffary, that at leaft one of the bodies fhould be in a fluid ftate.

It is evident that all folutions muft be the effect of an elective attraction. By *folution* I mean the difperfion of the particles of a folid body in a fluid in fo equal a manner, that the compound liquor fhall be perfectly and permanently tranfparent. In this cafe, therefore, it is plain that the particles of the fluid muft have a ftronger attraction for the particles of the folid body than they have for one another. A folid body may indeed, by mere mechanical means, be minutely difperfed through a fluid, but the compound in this cafe will be opake and muddy, and if fuffered to remain at reft, a fediment will immediately be depofited. Thus, if chalk or clay is incorporated with water, they will impart to

'nothing but a change of place; and as the copper is precipi-
'tated by the iron, fo the iron might be precipitated by pot-
'afh, or any other fubftance which has a greater affinity with
'the acid of vitriol than iron has.'

Watfon's Chem. Eff. p 234 to 236.

it

it their peculiar colour, and the fluid will be rendered in ſome degree opake; but if common ſalt, or blue or green vitriol is added to water, the fluid will ſtill remain perfectly tranſparent, though tinged with the peculiar colour of the ſalt. The former, therefore, is termed a *mixture*, the latter a *ſolution*. When a fluid has received ſo much of any ſolid body that it will not diſſolve a particle more, it is ſaid to be *ſaturated*.

The marks of chemical combination in bodies have been accurately defined by a correct and ingenious philoſopher. The firſt is a *ſpecific gravity exceeding that* of the *heavieſt ingredients* of the *compound*. Though he properly obſerves, it does not neceſſarily follow, that where ſuch denſity is wanting a chemical union does not exiſt; ſince the peculiar ſtructure of the compound, which does not admit water into its vacuities, may prevent this property from being remarked; or a quantity of water may enter into a compoſition naturally heavier than water, and yet cannot be always made ſenſible.

Secondly, Tranſparency is always a mark of chemical combination. Such union, however, is alſo ſometimes conſiſtent with opacity, as that effect may ſometimes ariſe from a mere mechanical arrangement of parts, from the interpoſition of ſome matter not properly combined, or from too great thickneſs.

Thirdly, *Cryſtallization* proves that the parts have been very minutely divided, and in general combined with the menſtruum (or fluid in which the

the bodies have been diſſolved). Other ſubſtances, however, may ſometimes intrude themſelves into the cryſtallized bodies, though not chemically combined with them.

Fourthly, A difficulty of diſſolving the compound body in the menſtruum, or fluid, which is a proper ſolvent for one or both of the component ſubſtances *.

It may be proper, before the concluſion of this ſection, to add a few words concerning one of the moſt curious effects of the attraction of combination, namely, *cryſtallization.* The word cryſtal is derived from *cryos* (froſt), and *ſtellô* (to contract); it was originally confined to a particular diaphanous ſtone reſembling clear ice, and was probably afterwards extended to all bodies which were tranſparent, and had their particles diſpoſed in a regular manner, particularly the different ſpecies of ſalts. It is now expreſſive of that regular order or diſpoſition, in which the particles of inert bodies arrange themſelves on paſſing from a fluid to a ſolid ſtate. This diſpoſition of the particles is, however, by no means the ſame in all ſubſtances, but varies almoſt infinitely in different bodies. Thus common ſalt cryſtallizes into a cubic form, ſalt-petre into that of oblong pillars with ſix ſides, cubic nitre into the rhomboidal form, vitriolated tartar and Glauber's ſalt into a maſs of four or ſix ſides. Each ſpecies of ſalt preſerves its peculiar form however frequently the proceſs of

* Kirwan's Mineralogy.

diſſolving

diſſolving it is repeated, and equally in the ſmalleſt maſſes which the microſcope renders viſible, and in the largeſt which art or nature have been able to produce *.

* ‘ If what has been ſaid relative to cryſtallization be not per-‘ fectly intelligible to the reader, I would adviſe him to make the ‘ following eaſy experiment, which will give him a better no-‘ tion of the matter than a thouſand words. Into a baſon full of ‘ boiling water, put as much ſaltpetre as the water will take up ; ‘ if the ſaltpetre was purified, the tranſparency of the water will ‘ not be injured, it will ſtill appear to be a homogeneous fluid : ‘ when the water will take up no more ſaltpetre, then he may ‘ conclude that it is ſaturated : let it ſtand without being ſtirred, ‘ till it grows cold. As it cools, a great many cryſtals, all of ‘ the ſame ſhape, may be ſeen ſhooting out from the ſides and ‘ bottom of the baſon, and increaſing in ſize till the ſolution be-‘ comes quite cold. When no more cryſtals can be formed by ‘ that degree of cold which prevails in the apartment where ‘ the experiment is made, pour the liquor from the ſolid cry-‘ ſtals ; this liquor is ſtill ſaturated with ſaltpetre ; and in order ‘ to make it part with more of its ſaltpetre, ſome of the water ‘ which keeps it diſſolved muſt be evaporated : upon the taking ‘ away a part of the water, a correſpondent part of the ſaltpetre ‘ loſes the power by which it is ſuſpended, and ought, upon that ‘ preſumption, inſtantly to fall to the bottom : yet it muſt be ‘ remembered, that the water from its increaſed heat during the ‘ evaporation, is able to ſupport more ſaltpetre than if it was ‘ cold ; and therefore the ſaltpetre will not begin to cryſtallize, ‘ notwithſtanding the loſs of part of its menſtruum, till the re-‘ mainder begins to cool. By repetition of this proceſs of eva-‘ poration and cryſtallization, we may obtain all the ſaltpetre ‘ which was at firſt diſſolved, as no portion of it can be evapo-‘ rated with that degree of heat which is uſed in evaporating ‘ the water.’

Watſon's Chem. Eſſ. p. 90 to 92.

It would perhaps be no raſh aſſertion to ſay, that the whole mineral kingdom appears in a cryſtallized ſtate; and this adds greatly to the probability that chemical combination or affinity is the great principle which has acted in the formation of all bodies. The cauſes of this peculiar diſtribution of parts are not to be demonſtrated, and on ſo abſtruſe a ſubject, all that we are able to perform is to produce ſome probable conjectures.

The old and fanciful chemiſts and alchemiſts, who remarked the curious figures which ſaline ſubſtances aſſumed during their cryſtallization, imagined that the ſalts ſtill retained the vegetative powers of the plants from which they were produced, and even thought they could obſerve the form of the plant in the cryſtallized maſſes. Later philoſophers have aſcribed to the primary parts of bodies a certain property which they call *polarity* (as analogous to that property of the *magnetic* needle) and which diſpoſes them to ſhoot out in certain directions *. A more probable opinion appears to be, that the minute particles of each cryſtallizing body are of ſuch a form that the ſides, which approach in contact, diſpoſe them in a particular direction.

From this regular arrangement of the parts it reſults that homogeneous bodies poſſeſs always an equal denſity in all their parts; and in moſt caſes, if nature is interrupted in the proceſs, the concrete

* Jones's Phyſiolog. Diſquiſ. 22.

will

will be imperfectly formed. So nice and critical is the arrangement of the parts in fonorous bodies, that it is faid the fmalleft vibration of the air occurring during the operation of cafting a bell, or rather while the metal is fettling in the mould, even the barking of a dog, will injure the tone *.

III. The attraction of GRAVITATION materially differs from the two preceding fpecies of attraction, fince it requires neither the particles of the bodies, nor the bodies themfelves, to be brought into immediate contact, but acts at confiderable diftances, and in this refpect it is analogous to the attraction of magnetifm and electricity.

The moft obvious effect of gravitation is the general tendency of bodies to the furface, or perhaps to the center of the earth. It appears to be one of the great laws of gravitation, that the attraction of bodies is in proportion to the quantity of matter they contain. The earth, therefore, being fuch an immenfe aggregate of matter, is fuppofed to deftroy the effect of this attraction between fmaller bodies, by forcibly compelling them to itfelf. The attraction of mountains, however, upon the balls of pendulums has been found, by repeated obfervations, to be very confiderable †.

The efficient caufe of this fpecies of attraction is as much a fecret as all the other great principles of nature. Some philofophers have fuppofed gravity to be one of the inherent properties of matter;

* Jones's Phyfiol. Difq. 22.

† Nicholfon's Introd. to Nat. Phil. V. i. p. 26.

others

others have afcribed it to the agency of a fubtle fluid; while others, with more modefty, and probably with more truth, have had recourfe to the immediate agency and interpofition of the divine power.

We are generally on fure ground when we defcribe effects. Ignorant as we neceffarily are of the caufes or inftruments by which the fupreme governor of the univerfe effects his purpofes, an attentive obfervation will commonly furnifh us with the obvious mode in which they generally take place. What philofophers term the laws of nature, are no other than the modes or forms in which her operations are ufually effected; and this is precifely the cafe with what are called the laws or properties of gravitation.

Firft, It appears that the gravitating force being proportioned always to the quantity of matter, all bodies gravitate from equal diftances with equal velocity, except prevented or impeded by fome refifting medium. Thus, though a guinea and a feather will not fall to the ground with equal velocity in the open air, becaufe of the refiftance of that fluid; yet if the air by any means is removed, as in the vacuum of an air pump, they appear to fall at the very fame inftant of time: for though the guinea contains confiderably more of folid matter than the feather, and confequently requires a more confiderable force to put it in motion, yet it appears that the attractive power being proportioned to the quantity of matter, its velocity is equal to that of of a body which requires lefs force to put it in motion.

Secondly, The attractive force of bodies is reciprocally as the fquares of the diftances. Thus, if a body is of the weight of one hundred pounds at the diftance of ten diameters of the earth, at half that diftance it would have four times that weight, or the force of gravity would be exerted upon it in a quadruple ratio, and fo in proportion as it approaches the body of the earth.

It would perhaps have been more correct to have fpoken of what is commonly called *fpecific gravity* in treating of the denfities or porofity of bodies, but the reafon why it was omitted on that occafion will prefently be apparent. The truth is, we have no mode of determining the denfity of bodies, but by the firft of thefe laws of gravitation, which have juft been noticed. For fince the force of attraction which nature exerts upon all bodies is in proportion to the quantity of matter which they contain, it follows of courfe, that if, of two bodies equal in bulk, the one is heavier than the other, that body is poffeffed of greater denfity, or contains more matter in the fame compafs.

The *fpecific gravity* is therefore the very fame thing with the *denfity* of bodies, and has relation to the quantity of folid matter which different bodies contain in the fame bulk. It is alfo called relative or comparative gravity, becaufe we judge of it by comparing one body with another. If bodies are equal in bulk, it is evident their fpecific gravities may

may be eaſily determined by a common balance, and hence fluids, or any bodies that may be eaſily reduced to the ſame bulk or form may eaſily be weighed and compared. By weighing accurately a determinate quantity of any fluid, an ounce for inſtance, in a phial, and marking preciſely the ſpace which it occupies in the phial, the weight of the ſame quantity of any other fluid may eaſily be had and compared with the former.

The ſpecific gravity of bodies which are not, nor can eaſily be reduced to an equal bulk, is not to be obtained by any method equally obvious to unphiloſophical perſons. A method, however, has been invented for determining the ſpecific gravities of ſolid bodies, whatever their figure or dimenſions. As it is an obvious principle, that every body when immerſed in a fluid muſt diſplace a quantity of the fluid equal to its own bulk, and the reſiſtance which it meets with from the fluid will be found exactly equivalent to the weight of the fluid ſo diſplaced; hence if any fluid, as water for inſtance, is taken as the ſtandard of compariſon, it will be eaſy to determine the ſpecific gravity of different ſolids by weighing them firſt accurately in air, and afterwards weighing them in water, and comparing their loſs of weight in this latter fluid, which will be in exact proportion to the ſpace which they occupy. To make this clear by an experiment; ſuppoſe it was neceſſary to determine the ſpecific gravities of any two metals, lead and tin for inſtance, I take a certain quantity of the former, and weighing it care-

fully

fully in air, I find its weight amounts to thirty-four ounces; on weighing it again in water, I find it weighs but thirty-one ounces, that is, it has loſt three ounces of its weight, or in other words, the ſame bulk of water would weigh three ounces; the ſpecific gravity of lead is therefore to that of water as 34 to 3 or as 11 $\frac{1}{3}$ to 1. On weighing a certain quantity of tin, I find again that it amounts to fifteen ounces, and on weighing it in water it appears that it has loſt two ounces of its weight. The ſpecific gravity of tin is therefore to that of water as 15 to 2, or as 7 $\frac{1}{2}$ to 1, conſequently the comparative gravities of the two metals are 11 $\frac{1}{3}$ to 7 $\frac{1}{2}$ *.

In the common tables of ſpecific gravities, the weight of water is eſtimated at 1, and that of other ſubſtances is exhibited in the ſame ratio. To determine therefore the ſpecific gravity of any ſubſtance heavier than water, weigh any given quantity of that ſubſtance in air in a common balance, and afterwards weigh it in water, carefully noting its loſs of weight; divide the whole abſolute gravity, or weight in air of the ſubſtance, by its loſs of weight in water, and you will have its ſpecific gravity.

IV. The attraction of MAGNETISM only differs from that of gravity in its operations being limited to particular ſubſtances. The *magnet* is an ore of iron, and its property of attracting certain portions of that metal at moderate diſtances is well known. Like the attraction of gravitation, that of magnetiſm

* Nicholſon's Philoſophy, V. ii. p. 11.

bears

bears a proportion to the diſtance, and probably to the quantity of matter (I ſhould ſay of magnetic matter) in the attracting bodies. But the properties of the magnet are ſo curious and important in nature that they well deſerve a diſtinct chapter.

V. The attraction of ELECTRICITY is alſo analogous to that of gravity in the property of acting upon bodies at a certain diſtance; but it differs from it in its operation being confined to a particular ſtate of thoſe bodies, that is, when excited by friction. But this peculiar ſpecies of attraction will be more amply treated of in a ſucceeding part of the work.

There is a property ſuppoſed to be incidental to matter, which is oppoſite to this of attraction, and which is therefore denominated REPULSION. It is a maxim of the Newtonian philoſophy, that where the ſphere, or power of attraction, terminates, that of repulſion begins. In the inſtance which has been already adduced of the round drops of dew upon the leaves of plants it is ſuppoſed not only that there exiſts an attractive force between the particles of the fluid, but a repulſive force between them and the leaf on which they are ſuſpended. That the drops are not in actual contact with the leaf is evident from their white or pearly appearance; for this appearance reſults from the copious reflection of white light from the flattened part of the ſurface contiguous to the plant; and it is well known that this effect could not take place, unleſs there was a real interval between the under ſurface of the drop

drop, and the contiguous surface of the plant*. The fact is also evident from another circumstance; the drop is not found to have the smallest adhesion to the leaf, but rolls off in a compact body with the greatest ease, which it could not do if the fluid was in actual contact with the leaf; or if there subsisted any degree of attraction between them.

In the same manner needles or other light metallic bodies will swim on the surface of a fluid. Flies walk upon water, and oil obstinately refuses to mix with that and other fluids. Hence the feathers of water fowl, which are covered with a thin coating of subtile oil, actually repel the surrounding water.

This principle of repulsion has, however, been disputed by some late philosophers; and all these effects have been accounted for by them, by supposing, not that there exists a positive principle of repulsion in the water, the oil, &c. but that the attraction of the leaf, of the water, &c. for the contiguous bodies is not sufficient to destroy the attraction which the particles of homogeneous fluids possess for each other.

The repulsion of magnetism and electricity will be treated of in those parts of the work which are appropriated to these subjects.

* Priestley's Optics, p. 454.

CHAP. IV.

OF MOTION AND REST.

Newtonian Theory of Motion and Rest.—Vis inertiæ.—Laws of Motion.

THE doctrines and laws of motion have a more intimate connection with the mechanical philosophy, than with a work which is strictly and literally physiological. As accidental properties of matter, however, motion and rest could not be wholly omitted in an investigation of the general principles of natural philosophy; though it will not be necessary to enter minutely into the detail of those mechanical powers which depend upon what are usually termed the laws of motion or of nature.

An attentive and judicious observation of the usual course of nature enabled Sir Isaac Newton to reduce the general principles or laws of motion to the three following axioms. There appears little necessity to illustrate them by particular instances, since they are confirmed by constant and universal experience; and however the application of these principles to the motions of the heavenly bodies, or to those departments of nature which are out of the reach of our observation, may be contested, their truth

truth and utility, with respect at least to those bodies with which we are best acquainted and have the most intimate connexion, will scarcely admit of dispute.

I. All bodies are perfectly indifferent to motion and rest. In other words, a body, if once at rest, will naturally remain so, unless disturbed by some power acting upon it; and a body in motion will continue that motion in the same direction, and with the same velocity, unless stopped or impeded by some external cause *.

The first part of this proposition is evident from every part of nature, since no part or portion of inanimate matter appears capable of giving itself any degree of motion. The latter part of the proposition, namely, that a body will continue its motion for ever, unless prevented by external force, it is not so easy to illustrate by experiment, since we are not able to produce any species of motion which is not in some degree counteracted by the force of gravitation, or by some resisting medium. The conclusion, however, appears to be fairly drawn, since the less the obstruction which is opposed to any body in motion, the longer the motion continues; thus a ball will continue longer in motion on a smooth than on an uneven surface, whence we may reasonably infer, that if all obstacles were completely removed, motion once communicated would never cease †.

* Pemberton's View, p. 29.

† See Enfield's Instit. Philosophy, p. 11, 12.

This property of reſiſtance in matter is termed, in technical language, its *vis inertiæ*.

II. The alteration of the ſtate of any body, whether from reſt to motion, or from one degree of motion to another, is always proportional to the force which is impreſſed, and in the direction of that force.

By this law, the degree of force is ſuppoſed to be meaſured by the greatneſs of the body which it can move with a given velocity. Thus a power which could give to a certain body ſuch a degree of celerity in its motion as to enable it to paſs in one hour the length of one thouſand yards, would give to another body, half as great as the former, twice the degree of velocity, and would enable it to paſs in the ſame time the length of two thouſand yards *. Hence the quantity of motion is always eſtimated by the ſwiftneſs of the motion, and the quantity of matter which is moved. If A and B, bodies of equal ſize, move with equal velocity, their quantity of motion is equal; but if A contains twice as much ſolid matter as B, and moves equally ſwift, it poſſeſſes a double quantity of motion †.

It follows evidently from the ſame law, that if a new force is impreſſed upon a body in motion, in the direction in which it moves, its motion will always be increaſed proportionably to the acceſſion of force, however frequently repeated.

* Pemberton's View, p. 29, 36.

† Elements of Nat. Phil. by Mr. Locke, chap. i.

It follows alſo, and may be proved by a very eaſy experiment, that if a new force is impreſſed upon a body not in the direction in which it moves, but in an oblique direction, the body will take a direction neither exactly the ſame as that in which it was proceeding, nor yet in the direction of the new force which is impreſſed upon it, but a direction between both. On this is grounded the commonly received opinion concerning the motion of the heavenly bodies. The centrifugal force is that which is ſuppoſed to have been impreſſed upon them at their firſt formation, and which would carry them forward in a direct line; this is counteracted by the force of gravitation (or centripetal force) which always inclines them to that body round which they revolve; the conſequence of theſe two forces acting in different directions is, that the bodies always move in a curve, or orbit, which is more or leſs elliptical as one of theſe forces happens to be predominant.

III. The third law is, that re-action is always equal to action *. In plain terms, the reſiſtance of a body at reſt, which is acted or preſſed upon, acts againſt a moving body with a certain degree of power, and produces the ſame effects as would have been produced by a certain degree of active force exerted in a direction contrary to that of the moving body. Hence it follows, that any one body acting upon another actually loſes as much force as it communicates, as will be evident, if with a ſmall

* Pemberton's View, p. 31.

bullet ſuſpended from a ſtring we ſtrike another bullet which is at reſt, or from obſerving a ball in motion on a billiard-table ſtrike another which is at reſt on the table; in both which caſes the ſtriking body will loſe half its quantity of motion, and that quantity of its motion which it loſes will be communicated to the other body *.

This law is an effect of the *vis inertiæ* of matter, and is extended to all caſes where there is a reſiſting body. When a load is drawn by a horſe, the load re-acts againſt the motion of the horſe, and the progreſſion of the animal is as much impeded by the load, as the motion of the load is promoted by the efforts of the animal. The finger which preſſes againſt any ſolid body is preſſed by that body; but in elaſtic ſubſtances the effect is moſt apparent,

* Enfield's Inſtitutes, p. 12, 13.

CHAP. V.

OF MAGNETISM.

Of natural and artificial Magnets.—Magnetic Powers.—Attraction.—Repulsion.—Polarity.—Declination.—Dipping of the Magnetic Needle.—Communication of the Magnetic Power.

THE properties of the magnet are illuſtrative of ſo many principles and laws of nature, that though, perhaps, not ſtrictly in order, I have determined to introduce the ſubject before the concluſion of this preliminary book; as ſome occaſions may ſhortly occur, when a reference to this topic may probably be uſeful, if not abſolutely neceſſary.

It is well known that every magnet is a ferruginеous body, and that its attractive force is confined in a great meaſure to ferrugineous ſubſtances. Magnets are of two kinds, natural and artificial. The natural magnet or loadſtone *, is a bog ore of iron; artificial magnets are formed either by being touched with a natural magnet, or by other different proceſſes, which will preſently be explained.

* *Load* (Sax.) or *leading* ſtone, probably from its being a guide to mariners.—*Adams on Mag.* p. 377.

The properly magnetic ores are calciform (refembling a calx or cinder) and are moftly of a dull brownifh black *. There are reddifh magnets found in Arabia; but moft of thofe in Europe refemble wrought iron in colour. Their hardnefs is juft fufficient to afford fparks with a fteel, and they are with difficulty attacked by a file. They differ confiderably in fpecific gravity, and feem to contain feveral fubftances befides iron in their compofition, fuch as argillaceous and filiceous earth. Mr. Kirwan is of opinion that fulphur enters into their fubftance, as the ore fmells of it when heated red hot: probably, alfo, they may fometimes contain nickel, as that metal, when purified to a certain degree, acquires the properties of the magnet.

Natural magnets are found more or lefs in almoft every iron-mine, of different fhapes, and of different fizes. Some old writers mention magnets that would fwim on water †; thefe were probably fome light, fpongy, volcanic fubftances, impregnated with iron. In Virginia there is a magnetic fand, which contains about one half iron. Thofe magnets which have the fineft grain poffefs the magnetic virtue in the higheft perfection, and retain it longer than any other ‡.

The great and well-known properties of the magnet are, 1ft, its attractive power; 2dly, its po-

* Kirwan's Min.—and Cavallo on Magnetifm.

† They are in general about feven times heavier than water.

‡ Kirwan and Cavallo.

larity,

larity, or difpofition to conform to the plane of the meridian; 3d, the property of dipping or inclining to the earth; and laftly, the power of communicating the magnetic virtues to other ferrugineous bodies.

I. Magnets attract clear iron more forcibly than any other ferrugineous body. The iron ores are attracted more or lefs forcibly, in proportion as they are impregnated with the metal, and in proportion as it exifts in a metallic ftate. The force of the attraction between a magnet and iron will depend in a great meafure on the weight and form of the iron; but art and obfervation have furnifhed us with no invariable rule in thefe refpects.

One magnet attracts another magnet in contact, with lefs force than it attracts iron; but the attraction between them begins at a much greater diftance than between the magnet and iron alone.

As iron is diffufed in greater or lefs quantities through almoft all the different bodies of which the univerfe is compofed, it is eafy to fuppofe that the natural bodies which are fubject to the magnetic attraction are very numerous. The perfect metals, gold, filver, and platina, as well as lead and tin, are however total exceptions; though their calces are a little attracted. Animal and vegetable fubftances alfo, though they are known to contain fmall portions of iron, feldom exhibit any difpofition to be attracted before combuftion *; though it is

* Cav. on Mag.

afferted

aſſerted that moſt ſubſtances may be rendered magnetic in ſome degree by being expoſed to the action of fire.

Iron is attracted with different degrees of force, according to the different modes in which it exiſts. It is, however, in no ſtate quite inſenſible to the magnetic power, even in the pureſt calx, or in a ſtate of ſolution. Soft iron is the moſt ſubject to a forcible attraction; ſteel is leſs ſo than iron, eſpecially when hardened, and the calces of iron in different degrees *.

Muſchenbroek, by a ſeries of experiments, endeavoured to aſcertain the force with which the magnet attracts at different diſtances. He ſuſpended a cylindrical magnet, 2 inches long and 16 drams in weight, to one ſcale of an accurate balance, and under it he placed a cylinder of iron of the ſame ſhape and bulk. The following is the force with which it attracted at different diſtances, eſtimated by the number of grains in the oppoſite ſcale.

At 6 inches	3 grains.
5 ———	$3\frac{1}{2}$.
4 ———	$4\frac{1}{2}$.
3 ———	6.
2 ———	9.
1 ———	18.
In contact —	87.

This experiment would perhaps have been more intelligible, if it had been previouſly remarked that the attraction between the magnet and the iron

* Cav. on Mag.

is

is always ſuppoſed to be mutual. If a magnet and a piece of iron are placed ſo as to float on the ſurface of water; the magnet will approach the iron, as well as the iron the magnet; or if either of them are kept ſteady, the other will approach towards it *.

Of natural magnets the ſmaller poſſeſs a greater attractive power, in proportion to their ſize, than the larger. There have been natural magnets of not more than 20 or 30 grains in weight, which would lift a piece of iron forty or fifty times heavier than themſelves; and mention is even made of one of about 3 grains, which lifted a weight of iron containing 746 grains, or 250 times its own weight †. What is yet more extraordinary, it not unfrequently happens, that a loadſtone cut off from a large one will itſelf lift a greater weight than the ſtone from which it was cut off. This circumſtance may reaſonably be attributed to the heterogeneous nature of the large loadſtone; for if we ſuppoſe that one part of it, *viz.* that which is cut off, contains a conſiderable portion of magnetic matter, and that the remainder is impure, of conſequence, while they remain in an united ſtate, the impure part will rather obſtruct the action of the other ‡.

The power of magnets is not at all times equally active; they will at one time attract at a much greater diſtance than at others. To what this variation is

* Adams on Magnetiſm, p. 385.

† Cav. on Mag. p. 36. ‡ ib. p. 37.

owing, is impossible to decide, while we remain so perfectly ignorant as we are of the causes of all the magnetic phenomena: probably it may depend upon the temperature of the stone, as the magnetic power is always diminished by heat.

There is in magnets a natural power of repulsion, as well as of attraction. Two magnetic bars, for instance, will attract each other if the two extremities or poles, which correspond in each, are brought within the sphere of attraction; but if the extremities which do not correspond are brought into contact, they will be mutually repelled *. This circumstance will be better understood when the polarity of the magnet has been properly explained. The power of repulsion is supposed by some experimentalists to be weaker than that of attraction.

II. The second distinguishing property of the magnet, is what is termed its *polarity*. In plain terms, if a magnet is placed in such a situation that it shall have liberty to assume that direction which is most natural to it, for instance if it is made to float on water upon a piece of wood or cork, if suspended by a slender string, or supported by a pivot, as is the needle in the common mariner's compass, it will dispose itself longitudinally nearly in the plane of the meridian, that is one extremity towards the north pole of the earth, and the other towards the south. The two extremities which correspond to

* Adams on Mag. p. 389.

the poles of the earth are called the poles of the magnet: and at these extremities the magnetic virtues seem to exist in their greatest force, as a magnet will support a much more considerable weight near the poles than at any other part *.

This property in the magnet has proved the basis of an invention the most useful to navigation that human sagacity ever discovered; as before this infallible guide was enlisted in the service of the mariner, the most adventurous pilot did not presume to trust himself out of the sight of land; consequently commerce is much facilitated by the discovery, and shipwreck is a much less frequent calamity. It was not till the thirteenth century that this circumstance was known. Authors are generally agreed at present, that a Neapolitan, of the name of John de Gioja, if not the inventor of the mariner's compass, was at least the first who made use of it in conducting vessels in the Mediterranean †. Some ridiculous pretences have been made by the Chinese to the honour of this, as well as of other European inventions; but the fables of that barbarous people, as well as of their encomiasts, the jesuits and infidels, are little to be regarded ‡.

Both the properties of attraction and repulsion have an intimate connexion with this of polarity. Thus, it is uniformly found to be the case, that in two magnets an attractive force obtains between

* Adams on Mag. p. 387. † Cav. on Mag.

‡ See Mr. Adams's Essay, p. 409.

the

the oppoſite poles, and a repulſive force between the poles of the ſame denomination. If, for inſtance, the north pole of the one is brought near the north pole of the other, a mutual repulſion will take place; but if the ſouth pole of the one is applied to the north pole of the other, they will be mutually attracted. And if, upon the ſame principles, a magnet is cut through the axis, the parts or ſegments of the ſtone, which before were united, will now repel and avoid each other *. If two magnets of a ſpherical form are freely ſuſpended, one will conform itſelf to the other, as to the poles of the earth. This influence of one magnet over another is termed the directive power, and this directive power acts at a greater diſtance than that of attraction. This may be proved by placing one magnet at the bottom of a ſcale, and holding the other at the ſame diſtance at which it acts in altering its direction: in this caſe no degree of attraction will be produced †. If a quantity of iron filings are gently duſted on a magnet, they will arrange themſelves around it in a very whimſical manner: this effect is only to be accounted for from the directive power of the magnet, for the filings by contact with the magnet aſſume the magnetic virtue, that is, become each of them a ſmall magnet, and arrange themſelves according to the polarity of the original magnet ‡.

* Adams on Mag. p. 444. † Cav. p. 98.
‡ ib.—Nicholſon's Phil. ii. p. 296.

Neither

Neither the directive nor the attractive power of the magnet is diminiſhed by the interpoſition of a foreign body. Steel filings ſcattered on a plate of metal, or of wood, or of any body not magnetic, will be affected by the motions of a magnet under the plate; and ferrugineous bodies are attracted with the ſame eaſe, and at the ſame diſtance, in the vacuum of an air-pump, as in the open air *.

Natural magnets are frequently found to have more than two poles. That is, the poles of another magnet of the regular form will frequently be attracted by different parts of the ſurface. This circumſtance depends on the form and heterogeneous nature of theſe irregular magnets: for a good loadſtone is always of an uniform texture, and has only two poles, which lie in oppoſite points of the ſurface, in ſuch a manner, that a line drawn from the one to the other would paſs through the center of the magnet †. When a magnet has more than two poles of equal ſtrength, the ſupernumerary poles may be ſo ſituated that the magnet will not, in the technical language, traverſe; in other words, it will not, when ſuſpended by a thread, &c. or when floating on water, aſſume the uſual direction to the poles of the earth ‡.

The magnetic meridian ſeldom coincides with the real meridian, but generally is found to vary a few degrees from the true direction of north and ſouth.

* Enfield's Inſtit. p. 340. † Cav. p. 40. ‡ ib. p. 43.

This is called the declination of the compafs. The magnetic needle varies fometimes to the eaft, and fometimes to the weft; and it varies not only in different places, but even in the fame place at different times. The declination at London is not the fame now as it was a few years ago *. Nay, fome

* The following table fhews the mean declination of the needle at different times in Paris and London.

Year.	Paris.	Year.	London.
	° ′		° ′
1580	11 30 E.	1576	11 15 E.
1610	8 0 E.	1634	4 5 E.
1640	3 0 E.	1657	0 0.
1666	0 0.	1665	1 22 W.
1670	1 30 W.	1692	6 0 W.
1700	8 12 W.	1730	10 15 W.
1728	14 0 W.	1756	15 15 W.
1771	91 45 W.	1774	21 16 W.
		1776	21 47 W.

Near the equator, in long. 40° Eaft, the higheft variation, from the year 1700 to 1756, was 17° 15′ Weft; and the leaft 16° 30′ W. In lat. 15° N. and long. 60° W. the variation was conftantly 5° E. In lat. 10° South, and long. 60° E. the variation decreafed from 17° W. to 7° 15′ W. In lat. 10° S. and long. 5° W. it increafed from 2° 15′ to 12° 45′ W. In lat. 15° N. and long. 20° W. it increafed from 1° degree W. to 9° W. In the Indian feas, the irregularities were greater, for in 1700, the weft variations feem to have decreafed regularly from long. 50° E. to long. 100° E. but in 1756 the variation decreafed fo faft, that there was eaft variation in long. 80°, 85°, and 90° E. and yet, in long. 95° and 100° E. there was weft variation.

In the year 1775, in lat. 58° 17′ S. and long. 348° 16′ E. it was 0° 16′ W. In lat. 2° 24′ N. and long. 32° 12′ W. it was 0 14′ 45″ W. In lat. 50° 6′ 30″ N. and long. 4° 0′ W. it was 19° 28′ W. Enfield's Inft. Phil.

 very

very nice obfervations feem to determine that the declination varies at different times of the day *.

The polarity of the magnet has been attempted to be accounted for, by fuppofing the earth a large loadftone, or at leaft that a mafs of ferrugineous matter, equivalent to fuch a loadftone, is contained within the bowels of the earth, to which all fmaller magnets muft neceffarily conform. Attempts have alfo been made to explain the variation or declination of the compafs upon fimilar principles. If the mafs of ferrugineous or magnetic matter which the earth contains is fuppofed to act upon all magnetic fubftances, and if this mafs is almoft conftantly varying its pofition and compofition by fubterraneous fires, it is not very difficult to fuppofe, that the magnetic needle will be fubject to confiderable variations from thefe important movements †.

The magnetic centre is the point between the two poles, where the magnet poffeffes neither attraction nor repulfion. If, however, a part of a magnetic bar is broken off at either pole, the fragment will ftill be a complete magnet, having two poles and a centre, though it originally might belong to a part of the magnet which was altogether of a certain polarity ‡.

III. Magnets, while they attract other bodies, appear themfelves to be fubject to the attraction of the earth; for a magnet, or magnetic needle, when placed fo as to be able to act according to its

* Adams on Mag. p. 415, 416. † Nicholfon's Phil.
‡ Cav. 218.

native impulſe, inclines one of its poles a little to the earth, while the other is proportionably elevated: this is called the *dipping* of the needle, and the inclination or dipping is found to be different in different latitudes. Near the equator the needle aſſumes a poſition almoſt perfectly horizontal; in the northern hemiſphere the ſouth pole is depreſſed or attracted to the earth; and in the ſouthern latitudes the north pole of the magnet ſuffers a ſimilar depreſſion.

This property of the magnet is accounted for upon the ſame principle as the former, namely, by ſuppoſing that the earth, from the quantity of ferrugineous matter which it contains, acts as an immenſe loadſtone, which at its poles attracts thoſe of every other magnet ſuſpended above its ſurface. It has more than once been repeated, that magnets attract each other at the oppoſite poles. Thus, if a ſmall magnet, or magnetic needle, is ſuſpended by a thread above a larger magnet, while its poles are at equal diſtances from the poles of the larger magnet, it will remain in a horizontal poſition; but if it is removed either one way or the other, that is, if one pole of the ſmaller magnet is moved towards the contrary pole of the larger, it will be attracted towards the perpendicular. This is exactly illuſtrative of the dipping needle, which upon the equator remains in an equilibrium, but inclines to the perpendicular as it approaches to the poles of the earth; and what is ſtill more agreeable to this theory is, that the dipping or inclination of the needle

needle is greatly increaſed as it approaches either pole.

IV. The magnetic virtue may be communicated to any ferrugineous body.

1ſt. By contact with a real magnet: and in this way artificial magnets are in general prepared. This property of imparting the magnetic powers is not, however, confined to the natural magnet, for artificial magnets are capable of communicating it to freſh ferrugineous bodies, and that without the leaſt diminution of their own power *: and the power may in this manner be communicated from one piece of iron to another to infinity. A weak magnet may alſo be rendered more powerful by the application of a ſtronger.

Soft iron acquires magnetiſm with more eaſe than hard iron or ſteel, but the virtue is not ſo permanent. Hard ſteel will retain it for many years without diminution.

To make artificial magnets of extraordinary power, ſome addreſs is required. A ſingle magnet cannot communicate a greater degree of power than itſelf poſſeſſes, but ſeveral magnets united will impart a power equal to their united force †. It will eaſily be imagined, that the power imparted will be in proportion to the approximation of the iron to

* It is ſaid indeed that the power of a magnet is increaſed rather than diminiſhed by communication.—*Cav.*

† Hence it is evident, that artificial may be made much ſtronger than any natural magnets whatever.—*Adams on Mag.* 378.

the magnet. To acquire a very high degree of magnetiſm alſo, the iron ought to remain ſome time in contact with the magnet.

There are ſeveral curious phenomena which attend communicated magnetiſm. The nature of the magnetiſm communicated will frequently depend upon the length of the iron bar which is brought into contact with the magnet. If, for inſtance, the north pole of a magnet is applied to the extremity of a long bar of iron, that extremity will of courſe acquire a contrary virtue, and become a ſouth pole; at a part of the bar, however, not very diſtant, there will be found a new north pole; at ſome diſtance again a ſouth pole; and ſo alternately, till the power is totally loſt; the number of theſe ſucceſſive poles depending on the ſtrength of the magnetiſm, and the length of the bar. If, however, the bar is of a moderate length, there will be only two regular poles *.

The polarity of a bar of iron may be altered by gradually moving the pole of a magnet along its ſurface. Thus, if the north pole of a magnet is applied to that extremity of a magnetic bar of iron which is the ſouth pole, and moved gradually along, the other (that is that which was the north) pole of the bar will in that caſe be converted into a ſouth pole †.

If a piece of wire which has been rendered magnetic is twiſted, its virtue will be ſtrangely interrupted and confuſed. In ſome parts it will attract,

* Cav. part i. c. 7. † Ib.

in others it will repel; and even in some places one side of the wire appears to be attracted, and on the other side repelled, by the same pole of a loadstone *. This and other phenomena seem to indicate, that much of the magnetic power depends upon the texture of the substance which retains it.

Every portion of iron is capable of retaining only a certain degree of the magnetic virtue. If a strong magnet is applied to a small piece of steel, the steel, while within the influence of the magnet, appears powerfully magnetic; but if the magnet is removed, the power subsides to a certain degree, which may be termed the point of saturation †. A number of magnetic bars, however, may be joined together, so as to form an exceedingly strong compound magnet ‡.

2dly. Iron is rendered magnetic merely by being kept a considerable time in a situation perpendicular to the surface of the earth; and in this hemisphere the lower extremity will be the north pole, and of consequence the contrary effect will take place in the southern hemisphere. This phenomenon also is explained from the magnetism of the earth, which communicates its power to ferruginous bodies, though by almost imperceptible degrees. Old iron bars in windows, &c. are frequently found to be strongly magnetic §.

* Rees's Cylop. art. *Magnet*; and Adams on Mag. 399.

† Cav. 92. ‡ Ib.

§ Lewenhook mentions an iron cross, which had acquired a very strong polarity.—*Adams*, 432.

The moſt advantageous ſituation of the bar is however not directly perpendicular, but rather in the direction of the dipping needle; and indeed the magnetic virtue which it acquires ſeems to be in proportion as it approaches that direction. Hard iron or ſteel acquires little or no magnetiſm from the earth, on account of its greater inſenſibility to the magnetic influence; but it is well known that iron hardens by expoſure to the atmoſphere; it has been ſaid, therefore, that bars of ſoft iron, which have remained for a long time in a magnetic direction, have acquired as ſtrong a power as good natural magnets *.

A bar of iron made red hot, and left to cool, or quenched in water in the poſition of the dipping needle, acquires a degree of magnetiſm proportional to its nature, and the circumſtances of its cooling †.

3dly. Magnetiſm may be imparted to a bar of iron, by placing it firm in the direction of the dipping needle, and rubbing it hard one way with a poliſhed ſteel inſtrument ‡.

4thly. Any violent percuſſion will impart polarity, and the other magnetic virtues, to a bar of iron in a vertical poſition. A few ſtrokes of a hammer will produce this effect; and by hitting firſt one end of the bar, and then the other, the poles may be changed. If a long piece of wire is twiſted ſeveral times backwards and forwards, and then broken off

* Cav. † Adams, and Cav. ‡ Nicholſon's Phil. 292.

at the twifted part, the broken end will be magnetic *.

5thly. Even hard iron tools, when heated by any brifk action, as hammering, filing, &c. acquire an impermanent magnetifm, and, while warm, attract thin filings, or fmall portions of iron †. This fact, I am inclined to fufpect, muft depend in a great meafure on the unequal texture of thofe tools: if we fuppofe them to be compofed of hard and foft particles, the latter will eafily acquire an impermanent magnetifm.

6thly. Apparently all the three laft-mentioned effects depend upon precifely the fame caufe; and, perhaps, we may add to thefe, the magnetifm which is produced by electricity. If a bar is laid horizontally to the magnetic meridian, and fubjected to the electric fhock, whatever may be the direction in which the fhock enters, that extremity which is pointed towards the north, will be the north pole; and if the bar ftands perpendicular, it will follow the ufual law of communicated magnetifm, that is, in this hemifphere, the end which is next to the earth will be the north pole ‡. Lightning is the moft powerful of all natural agents in producing immediate magnetifm; it will, in an inftant, render hardened fteel ftrongly magnetic, and will invert the poles of the magnetic needle §.

One of the moft fingular properties of the magnet is, the increafe of power which may be added to

* Adams on Mag. 444. † Rees Cyclop. art. *Magnet.*
‡ Cav. § Adams on Mag. 398.

it by gradually increasing the weight it sustains; and on the other hand, it will gradually, by disuse, lose much of its natural strength *. If a magnet is hung up with a weight of iron, as much as it will for the present sustain, by adding gradually, suppose a few grains daily, it will at length acquire the power of attracting near double the weight which it would have attracted at first. It is probable, however, from what was formerly remarked, that this power has a limit.

If a piece of iron, somewhat more ponderous than a magnet will sustain, is applied to the pole of the magnet, it is plain that on removing the hand the iron must fall. But if another piece of iron is held at some little distance below the first, the magnet will be able to support it. The reason is, that both pieces of iron being rendered magnetic, the first piece is actually converted into an artificial magnet, by its contact with the original, and its virtue is increased by the second piece of iron, consequently it is rendered capable of a greater degree of attraction for the original magnet †. To make this perfectly clear, it is necessary to be observed, that a piece of iron, brought within a certain distance of a magnet, becomes itself possessed of all the magnetic properties, and that part of the iron which is nearest the magnet acquires a contrary polarity. Thus, if a magnetic chain is composed of several pieces of iron, each piece is in itself a complete magnet, and they

* Cav. 25. † Cav. 200.

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mutually ſtrengthen the magnetic virtue of each other *, as all magnets in contact are known to do.

The magnetic virtue is DIMINISHED:

1ſt. By *diſuſe:* particularly if the magnet is laid amongſt iron, or permitted to ruſt. Magnets will alſo be injured, unleſs they are kept together with the oppoſite poles correſponding, the ends being connected by pieces of iron; and they ought never to touch, except when in this poſition. The ſouth pole ſhould always be employed in this hemiſphere to lift iron; and a ſtrait magnet will be weakened, unleſs kept with its ſouth pole to the north in the direction of the magnetic needle, or downwards in that of the dipping needle †.

2dly. *Heat weakens the power of a magnet*; and that high degree which is called by chemiſts a white heat, entirely deſtroys it ‡. On this principle Mr. Canton endeavoured to account for the daily variation of the compaſs; as ſuppoſing it to depend on the heating and cooling of the magnetic ſubſtances within the earth. This theory he illuſtrated by the following experiment:—About E. N. E. from a compaſs he placed a ſmall magnet, exactly at ſuch a diſtance, that the power of the magnet at the ſouth pole was juſt ſufficient to keep the north end of the needle to the N. E. point, or 45 degrees. He contrived to heat the magnet, by putting upon it a braſs

* See Cav. p. 30 and 203.

† Adams on Mag. 397, 443. ‡ Cav. 35.

veſſel,

veſſel, into which he poured about two ounces of boiling water, and as the magnet gradually heated, he obſerved, during ſeven or eight minutes, that the needle moved about three-quarters of a degree weſtward, and became ſtationary at 44¼°; in nine minutes more it came back a quarter of a degree; but it was ſome hours before it gained its former ſituation, and ſtood at 45° *.

3d. In general the ſame means which facilitate the communication of magnetiſm to ferrugineous bodies not magnetic, tend to deprive thoſe which really are ſo of the magnetiſm they have acquired. Every kind of violent percuſſion weakens the power of a magnet; and a very ſtrong magnet has been entirely deprived of its virtue by receiving ſeveral ſmart ſtrokes with a hammer †. This effect appears to depend chiefly on the derangement of the particles in the magnetic bodies. Thus, if a dry glaſs tube is filled with iron filings, magnetiſm may be communicated to the tube by touching it with a loadſtone, exactly as if it was an iron bar; but the leaſt agitation which diſturbs the ſituation of the filings will preſently expel the magnetic virtue ‡.

4th. In the ſame manner the electric ſhock, which imparts the ſtrongeſt virtue to iron not previouſly magnetic, will diminiſh, and even deſtroy, the power of a real magnet. Electricity will alſo ſometimes invert the poles of a magnet §.

* Adams on Mag. 417. † Ib. 443. ‡ Ib. 444.

§ Cav. part i. c. 7; and Adams on Mag. 446.

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The phenomena of magnetiſm ſtand alone among the wonders of philoſophy, unleſs we ſuppoſe the attraction of gravitation to be a ſpecies of general magnetiſm, which indifferently affects all the various bodies of which this univerſe is compoſed. Certain analogies have been traced, or rather imagined, between electricity and magnetiſm. Both powers are excited by friction; and the magnetic polarity has been compared to the two ſtates of poſitive and negative electricity. The analogy is favoured alſo by the poſſibility of imparting the magnetic virtue to iron by the electric ſhock; and the Aurora Borealis, which is generally accounted an electrical phenomenon, is ſuppoſed to have ſome influence on the variation of the magnetic needle. Theſe powers, nevertheleſs, I muſt avow, appear to me eſſentially different. The phenomena of electricity are not at all times exhibited by electrical bodies, but merely when thoſe bodies are in a ſtate of excitation. When the electrical virtue is imparted from one body to another, the body that imparts it loſes proportionably of its own power, but the magnet rather increaſes than diminiſhes its ſtrength by communication. The electric matter is viſible; whereas the very exiſtence of a magnetic fluid is juſtly queſtionable; beſides that electricity, both in its nature and effects, bears ſo cloſe an analogy to another apparently very different power in nature, that there can be no reaſon for referring it to one with which it appears to have a very ſlight, and, moſt probably, only a caſual, agreement.

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The polarity of the magnet, as well as the dipping of the needle, are in all probability mere effects of its great property, attraction, ſince they appear to be fairly accounted for, from the ſtrong and peculiar attraction which the magnet appears to have for the earth, or rather for that immenſe maſs of ferrugineous matter which the earth contains. The attraction of the magnet is commonly ſuppoſed to depend upon the agency of a ſubtile fluid which circulates around it, enters the pores of the magnet itſelf, and of all the bodies which it attracts. I confeſs that the theories which are founded upon this hypotheſis appear to me ſo deficient in the only proof that ought to be admitted in natural philoſophy, I mean actual obſervation, and I am ſtill inclined to account the cauſe of magnetiſm as one of the undiſcovered principles of philoſophy. I am not fond of indulging the imagination in its favourite propenſity to create inviſible agents in order for the fabrication of plauſible theories, which ſome ſlight and caſual experiment may ſhortly overturn. We appear to be equally ignorant of the nature of gravitation, and of the common attraction of coheſion and combination. It is a trite remark, that there are certain points at which the human faculties muſt ſtop in all our ſpeculations. This would be a dangerous tenet, if it promoted indolence, or diſcouraged our ardour in the purſuit of natural knowledge by the only ſecure path, I mean that of experiment; but it is a ſalutary maxim when applied to the imagination, and when it only ſerves to reſtrain our

our ardour for fabricating ſyſtems, which have no other end but to remove for a moment the uneaſy but uſeful ſenſation of doubt and curioſity.

I ſhall not therefore incumber my work with the detail of ſyſtems to which I do not feel inclined to aſſent; but for a clear, and, I think, correct, ſtatement of the moſt plauſible theories concerning the cauſes of magnetiſm, ſhall content myſelf with referring my reader to an author to whom I have many obligations, and whoſe loſs, as a friend, I can never ſufficiently lament; and ſhall direct him to conſult the late Mr. Adams's ingenious Eſſay on this ſubject *.

* Printed in the ſame volume with his Eſſay on Electricity. In the ſame Eſſay the reader, who wiſhes to entertain himſelf with the practical and experimental part of magnetiſm, will find proper and eaſy directions.

Book II.

OF THE NATURE OF FIRE.

Chap. I.

HISTORY OF THE DISCOVERIES RELATIVE TO FIRE AND HEAT.

Opinions of the Ancients.—Of Bacon, Boyle, and Newton.—Of Homberg, Sgravesend, and Lemery.—Invention of the Thermometer.—Opinion of Boerhaave.—Great Discovery of Dr. Black.

SO wonderful is the nature, ſo extenſive is the action, and ſo eminent is the power of fire, that by one of the greateſt nations of antiquity * it was adored, as the embodied preſence of the ſupreme God: and even in countries where the adoration was leſs palpable and direct, ſomething myſterious was always attributed to this ſubtile and aſtoniſhing element; and the rites and myſteries of fire were celebrated in temples and in groves, from the ſhores of the Helleſpont to the banks of the Tiber.

An opinion ſeems to have been prevalent among the early philoſophers of Greece, that fire is the

* The Perſians.—See Herod. Lib. III. c. 18.

only

only elementary and homogenial principle in nature, and that from its different modifications all this variety of different bodies is produced *. This idea is ridiculed by Lucretius, who adopts the fyftem of Epicurus: and indeed the Epicureans, as well as the Peripatetics, feem to have confidered fire as a diftinct elementary fubftance, capable of combining with the other elements, but by no means the matter from which they are originally generated.

The hiftory of error can afford but little inftruction, otherwife volumes might be filled with the fantaftical opinions which have been from time to time entertained concerning the element of fire. On the revival of letters and philofophy, our illuftrious Bacon, in a treatife exprefsly written upon the fubject †, endeavours to prove, that heat is no other than an inteftine motion or vibration in the parts of bodies; and he was followed by moft of the philofophers of this kingdom during the laft century. The opinion of Bacon is fupported by a variety of facts, which are adduced by Mr. Boyle in a differtation on the *mechanical origin* of *heat and cold* ‡; nor does the fyftem appear repugnant to the fentiments of Newton; though he fpeaks of it with that diffidence which is always obfervable in his writings,

* Lucret. lib. i. 636. † De forma Calidi.

‡ Mr. Boyle, however, though thus apparently deceived with refpect to the caufe of heat, in another effay reafons juftly with refpect to its effects. He confiders ice not as the preternatural ftate of water, but water as ice preternaturally thawed by heat. *Boyle on the nat. and preternat. State of Bodies.*

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when treating of facts not absolutely demonstrated by experiments of his own *.

Notwithstanding the reputation of the English philosophy, this theory was received with great reluctance abroad. The celebrated Homberg, Sgravesend, and Lemery the younger, assert, that fire is a distinct substance or body, which enters into combination with all other bodies, pervades all bodies, and may be again expelled from them by violent motion or compression, though the fire is certainly not generated by such motion †.

One of these philosophers (M. Lemery) indeed carried his system much further, and made a very near approach to the received doctrines of the present day. He asserted, that fire is not only contained in those bodies which are inflammable, but even in water itself. Ice he affirmed to be the natural state of water; and he added, that the fluidity of that substance is a real fusion, like that of metals exposed to the fire, only differing as to the quantity of heat necessary to preserve it in fusion ‡.

About the commencement of the last century instruments were first contrived for measuring the heat of bodies by the degree of expansion; and this invention seemed to give some colour to the hypothesis of the German philosophers, since it is not very clear how a mere increase of motion can in-

* Optics, 318, 349.

† The reasons in support of each of these theories will be considered in the following chapter.

‡ Mem. de l'Acad. Roy. 1709.

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creaſe the extent of bodies. It was long obſerved, that all bodies are expanded by an increaſe of heat; and it was evident that fluid matters were affected more than ſolids. The firſt ſubſtance therefore that was employed, was the very expanſible and elaſtic fluid *air*; a quantity of this fluid was incloſed within a ſmall tube, with a ſmall drop of oil, or ſome coloured liquor, at the top, which ſerved to ſhew the expanſion which the incloſed air underwent from the increaſe of temperature. As this thermometer, however, was open at the top, it was alſo found to be affected by the external air; tubes hermetically ſealed were therefore preſently ſubſtituted, and the coloured liquors themſelves were found to be ſufficiently expanſible to mark the degrees of heat. Spirit of wine was employed by the Florentine academicians, and oil was afterwards made uſe of by Sir Iſaac Newton; who conſtituted the points at which water freezes, and that at which the ſame fluid boils or aſſumes the form of vapour, as extreme points of his ſcale of heat. Theſe thermometers were however ſuperſeded, at leaſt in England and Germany, by the invention of Olaus Roemer, afterwards improved by Fahrenheit, who ſubſtituted mercury in the place of the other fluids which had previouſly been employed in the conſtruction of thermometers.

The ſagacious and learned Boerhaave, both by his own experiments and by his attention to thoſe of others, contributed greatly to the elucidation of the doctrine of heat and fire. He was a ſtrenuous aſſerter of the exiſtence of fire as a diſtinct elemen-

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tary ſubſtance. Expanſion or rarefaction he conſiders as the uniform ſign or criterion of its exiſtence in other bodies. The production of fire from the attrition of two hard bodies, as a flint and ſteel, or two pieces of hard wood, &c. he accounts for, by ſuppoſing that the parts of theſe bodies will every moment be violently compreſſed, which will excite in them, by their re-action, a vibratory motion, and this will neceſſarily excite and expel the fire which exiſted latent in their pores; and as fire is capable of being produced in this manner by the violent attrition or motion of all bodies, he infers that it is preſent through every part of nature; yet, ſince it is expelled by the attrition or vibrations of the particle , he thinks it is clear that it does not penetrate the integrant or elementary particles of bodies, but exiſts only in their pores or interſtices. As fire is ſuppoſed to exiſt in all bodies, he proves its exiſtence in air and water; and agrees in opinion with the younger Lemery, that ice is the natural ſtate of water, and that it is kept in a fluid ſtate by a quantity of fire which it abſorbs.

There is a period when the minds of men are prepared for the reception, as well as for the proſecution, of great diſcoveries in ſcience. The hints, for they are little more, which had been afforded by theſe philoſophers, appear to have made little impreſſion; and the nature of heat, fire, and fluidity ſeems to have been involved in obſcurity and contradiction, till the genius and induſtry of Dr. Black, of Edinburgh, developed a ſyſtem, which explains

ſatisfactorily

satisfactorily a variety of the most curious and difficult phenomena in nature. By a number of nice observations, he was enabled to determine that absolute heat or fire was absorbed by all bodies whatever, and that it was absorbed in greater quantities by fluid than by solid substances; heat therefore he considered as the cause of fluidity. He found further, that bodies in passing from a solid to a fluid state absorb a quantity of heat without increasing their temperature or sensible heat, as manifested by the thermometer. Thus, if water with a quantity of solid ice is set over the fire, the temperature of the water will not be increased, but will continue at the heat of 32 degrees, the freezing point, till every particle of the ice is dissolved. The reason is, that fire being absolutely necessary to impart fluidity to any body, in proportion as the ice becomes fluid the superfluous fire is absorbed. In the same manner, when the fluid is converted into vapour, a quantity of absolute heat or fire is absorbed without any increase of temperature above the boiling or vapourific point. This discovery Dr. Black was led to by heating water in a close furnace a considerable degree above the boiling point; when on opening the vessel in which the water was confined, he found that a small quantity of the fluid burst out suddenly in the form of vapour, and the temperature both of the vapour and of the remaining water immediately sunk to the boiling point. It was evident therefore that the superfluous heat was absorbed by the vapour, and as the quantity of water which was lost by the

 process

procefs was not great, it followed that a confiderable quantity of the matter of heat or fire is neceffary to keep water in a ftate of vapour. When any quantity of heat is expelled from a body, in fuch a manner as to affect our touch, it is termed, according to Dr. Black's theory, *fenfible* heat; and when it is abforbed by any body, and exifts in combination with that body, either in a fluid or vapourific ftate, it is termed *latent* heat. It is alfo evident from what has been ftated that the opinion of thefe later philofophers is, that heat or fire, which has alfo been called *igneous fluid*, *matter of heat*, and lately by the French chemifts *calcric*, is a diftinct fubftance or fluid, which has an attraction for all other fubftances; that it pervades moft bodies; that it is the only permanent fluid in nature, and the caufe of fluidity in all other bodies. That not only common fluids, fuch as water, but all elaftic fluids, fuch as vapour and air, owe their exiftence in that ftate to the prefence of heat; and that it is fubject to all the laws of attraction, and is more forcibly attracted by fome bodies than by others.

The fchool of Dr. Black feems to have confidered light and heat as effentially different; and Dr. Scheele, a Swedifh philofopher, has endeavoured to prove, that light is formed by an union of the matter of heat with phlogifton or the inflammable principle: but this theory is now exploded.

Upon the theory of Dr. Black, the late ingenious Dr. Crawford * has founded a very curious fyftem concerning

* I cannot mention this truly amiable philofopher, without a fhort tribute to his memory, though it has apparently little connection

concerning the generation of heat within animal bodies, which he confiders as derived from the air we breathe. The air being condenfed on the lungs, the heat which it contained in a latent ftate is abforbed and difperfed over the animal body.—But this is a fubject which properly belongs to another part of the work.

connection with the fubject. No man was ever better calculated for promoting ufeful fcience than Dr. Crawford. In him induftry and perfeverance were eftablifhed habits; and candour and caution characteriftic difpofitions. With all the advantages of a liberal education, he united great natural fagacity, acutenefs, and ingenuity; yet the laft quality was tempered by a coolnefs and collectednefs of mind, which effectually prevented his too haftily acceding to the rafh conclufions of plaufible theory. With all his excellence as a fcientific man, he poffeffed the gentleft of tempers, the moft friendly heart.—From his promifed revifion of this work, I had flattered myfelf with great advantages; but what are private loffes, compared with that of the public! If, after having ferved his country in a public capacity, the family of fuch a man fhould be left in indigence, to what a ftate is the national fpirit reduced!

Chap. II.

OF FIRE (CALORIC) AND ITS PROPERTIES.

Inquiry whether Heat or Fire is a Subſtance or Quality.—Fire a Body.—Application of this Doctrine.—Analogy between Heat and Light—Objections.—Properties of Fire or Caloric; Minuteneſs of Particles; attracted by all Bodies.—Conducting Powers of different Bodies.—Cauſe of Fluidity.—Why Heat is produced by ſlacking Lime, and by certain Mixtures of cold Subſtances.—Freezing of Water by the Fire Side explained.—Fire the moſt elaſtic of all Bodies.

THE element of fire is only known by its effects; ſo ſubtile and evaſive indeed is this wonderful fluid, ſo various are the forms which it aſſumes in the different departments of nature which it occupies, that its very exiſtence, we have ſeen, has been queſtioned by ſome philoſophers.

Heat, ſay theſe theoriſts, is nothing more than an inteſtine motion of the moſt ſubtile particles of bodies. Fire is no other than this motion increaſed to a certain degree, in other words, a body heated very hot; and flame is no more than ignited vapour, that is, vapour, the particles of which are agitated in an extraordinary degree.

In ſupport of this theory it is alledged, 1. That motion in all caſes is known to generate heat; and if continued to a certain degree, actual ignition will be produced,

produced, as the friction of two pieces of wood will firſt produce heat, and afterwards fire; and the motion of a glaſs globe upon an elaſtic cuſhion will cauſe a ſtream of fire to be copiouſly emitted. 2dly, Bodies which are moſt ſuſceptible of inteſtine motion, are moſt readily heated. 3dly, Motion always accompanies fire or heat, as is evident on mixing oil of turpentine and vitriolic acid; and the heat ſeems in moſt caſes to bear a proportion to the degree of motion or agitation. In the boiling of water, and in the hiſſing of heated iron when applied to a fluid, this motion is evidently manifeſted. 4thly, If the particles of any body are excited to a violent degree of inteſtine motion, by attrition, fermentation, &c. if they do not actually emit flames, they will yet be diſpoſed to catch fire with the utmoſt facility; as in the diſtillation of ſpirits, if the head of the ſtill is removed, the vapours will inſtantly be converted into flame if brought into contact with a lighted candle, or any other ignited body. Laſtly, Heated bodies receive no acceſſion of weight, which they apparently ought to do, on another body being introduced into their pores.

Plauſible as this reaſoning appears at firſt ſight, the hypotheſis which aſſigns exiſtence to the principle of fire, as a diſtinct elementary principle, is ſupported by more numerous facts, and by more deciſive reaſons; it accounts better for all the phenomena of nature, and even for thoſe very phenomena which are adduced in ſupport of the contrary opinion.

1ſt. If it is admitted, as I apprehend it muſt, by the advocates for the contrary opinion, that the internal motion or agitation, which they ſay conſtitutes heat, is not equally felt by all the component particles of bodies, but only by the minuter and more ſubtile particles; and that theſe particles being afterwards thrown into a projectile ſtate produce the effect of light; theſe conceſſions will almoſt amount to the eſtabliſhment of the principle of fire as an elementary principle.

2dly. That fire is really a ſubſtance, and not a quality, appears from its acting upon other ſubſtances, the reality of which has never been doubted. Charcoal, in its natural ſtate, contains within its pores a large quantity of air; but if charcoal is heated, this air is expelled by the fire, which aſſumes its place, and occupies the pores of the charcoal. The burning of lime alſo, which deprives it of a great part of its weight by expelling the fixable air, demonſtrates that fire, as a ſubſtance, enters into the pores of the lime, and forces out thoſe other ſubſtances which are leaſt intimately combined with it.

3dly. All the evidence of our ſenſes, and many indubitable experiments, prove that light, which many ſuppoſe to be fire in a projectile ſtate, is a ſubſtance. Boerhaave concentrated the rays of the ſun in a very ſtrong burning-glaſs, and by throwing them upon the needle of a compaſs, the needle was put in motion by the force of the rays, as it would have been by a blaſt of air, or a ſtroke from ſome other body. But this experiment was purſued with ſtill ſuperior

ſucceſs,

ſucceſs, by a late ingenious philoſopher *. He conſtructed an inſtrument, in the form of a ſmall vane or weather-cock. It conſiſted of a very thin plate of copper, of about one inch ſquare, which was attached to one of the fineſt harpſichord wires, about ten inches long. To the middle of the wire was fixed an agate cap, ſuch as is uſed for the ſmalleſt mariners compaſſes, after the manner of which it was intended to turn; and the copper plate was balanced on the other ſide by a grain of ſmall ſhot. The inſtrument weighed ten grains; and to prevent its being affected by the vibrations of the air, it was incloſed in a glaſs box. The rays of the ſun were thrown upon the plate of copper from a concave mirror of two feet in diameter; in conſequence of which the vane, or copper plate, moved on repeated trials with a gradual motion, of about one inch in a ſecond of time. This experiment I think a ſufficient demonſtration, if any demonſtration was wanted, that light at leaſt is a body. Of the identity of light, heat, and fire, I ſhall have occaſion afterwards to treat.

4thly. The electric fire affects bodies with a true corporeal percuſſion †; and that this effect is not owing to the vibration of the air, or any medium but that of fire itſelf, is proved by many experiments

* Mr. Mitchell.—See a fuller deſcription of his inſtrument and experiments, in the Phil. Tranſ. and Prieſtley's Optics, p. 387.

† Jones's Phyſiol. Diſq. p. 85.

in vacuo, &c. Now, if one ſpecies of fire is allowed to be material, there ſeems to be no reaſon why we ſhould deny the ſame attribute to the reſt.

5thly. It is not eaſy to conceive how a body can be expanded by motion alone; and it is much more natural to ſuppoſe, that bodies are expanded by the interpoſition of an extremely active and elaſtic ſubſtance between their component particles.

6thly. It is well known that there can be no ignition or combuſtion, that is, there can be no very high degree of heat, without a ſupply of air; a candle, for inſtance, will ceaſe to burn in vacuo, or in air, the pure part of which is deſtroyed by burning or reſpiration. This is a fact which cannot be accounted for on the principle that all heat is no other than inteſtine motion; but is eaſily explained if we ſuppoſe fire a diſtinct elementary ſubſtance, which is contained in pure air, and is yielded by the air to the force of a ſuperior attraction.

6thly. That heat is generally accompanied by motion, is no proof that heat and motion are the ſame; on the contrary, nothing is more natural than that the entrance of an exceedingly elaſtic ſubſtance into the pores of another body ſhould excite ſome degree of inteſtine motion, as well as the emiſſion of the ſame ſubſtance, which muſt occaſion ſome degree of contraction in the particles of the body. Heat is indeed excited by the attrition of two pieces of wood; but why may not the fire in that caſe be expelled from the wood by the vibration

tion or contraction of its fibres *, or from the air which occasionally interposes itself? In the same manner a piece of lead will become hot by hammering; but lead, and all metals, are known to contain a quantity of fire in a latent or combined state, which indeed occasionally causes their expansion or dilatation; it is then the more probable supposition, that the fire is expelled from the lead by the hammering and contraction of the metal, and this is rendered still more probable, since the contraction or compression of the metal in a vice will produce the same effect. The instance taken from the inflammability of the steam of spirituous liquors will be perfectly explained when I speak of steam or vapour; besides that, these liquors are among the most inflammable substances with which we are acquainted, and their particles, being in a rarefied state, will be more subject to those natural forces, which in all states are known to act upon them. There is no increase of gravity in heated bodies, because of the great elasticity of the matter of fire, which expands the bodies into which it enters, and consequently rather diminishes their specific gravities.

7thly. All the other phenomena of nature are more satisfactorily accounted for, on the principle that fire is a distinct substance, than on that which supposes it a mere quality, depending on the tremor or intestine motion of bodies.

* If the parts of a body, containing any fluid, are made to vibrate strongly, they will in general expel a part of the fluid out of the pores.—*Nicholson*, Vol. II. p. 122.

Heat

Heat and light are the only means by which we are enabled to difcover the prefence of fire; I conclude, therefore, that they are both effects of the fame caufe. The rays of the fun, when concentrated to a certain degree, produce intenfe heat; and heat, when violently excited by attrition, &c. if the body in which it is excited is in favourable circumftances, will generally terminate in flame, and confequently in the emiffion of light. This hypothefis receives a ftrong confirmation from an experiment of Mr. Boyle. He coloured the furface of a large tile, one half white, and the other black: after fuffering it to lie for fome time, expofed to the fummer fun, he found that while the whited part of the furface, or that part which reflected back the rays of light, remained quite cool, the black part, which imbibed them, was grown extremely hot. He occafionally left a part of the tile of its native red; and, after expofing the whole to the fun, found that this part grew hotter than the white, but not quite fo hot as the black part. He obferves, that rooms hung with black are not only the darkeft but the warmeft alfo; and a virtuofo of unfufpected credit affured him, that in hot climates he had feen eggs well roafted in a fhort time, by only blacking the fhells, and expofing them to the fun. This fact was afterwards completely eftablifhed by Dr. Franklin, who expofed feveral pieces of cloth of different colours upon the furface of fnow; he found that the black funk confiderably beneath the furface, confequently that

that it imbibed a large quantity of heat, whereas the white, which reflected the greater part of the rays of light, had imbibed fcarcely any heat whatever.

The only objection of any moment, which has arifen againft this doctrine is, that there exift certain bodies, fuch as what are called the folar phofphori, putrefcent fubftances, and rotten wood, which emit or reflect light, without apparently poffeffing the fmalleft quantity of fenfible heat. If however we confider the extreme weaknefs of the light which is emitted by thefe fubftances, the objection will appear to have little force. The moft concentrated moonlight, in the focus of a concave mirror, is not more than the three hundredth part of the intenfity of common funfhine *; and yet the light from thefe fubftances is not to be compared with that of the moon. Nay, the analogy between heat and light receives confirmation from thefe very fubftances; for the property which they poffefs of emitting light, is greatly increafed by an acceffion of heat; and even phofphori, in which the light has for fome fpace of time been dormant, or in which it is apparently exhaufted, will emit light upon the application of heat alone †.

I conceive fire therefore, or caloric, as termed by the French chemifts, to be the elementary principle or caufe of heat and light. Fire in a difen-

* See a note by the ingenious tranflator of Fourcroy's Lectures. Vol. I. p. 123.

† Prieftley's Optics, part iv. f. 1.

gaged

gaged ſtate, or in the act of paſſing from one body to another, impreſſes our organs with the ſenſe of heat; and fire, in a rarefied and projectile ſtate, probably conſtitutes the matter of light. Conſiſtently with theſe principles, the ſun may be conſidered as the great ſource of fire, whence it is diſtributed to all the different bodies in our ſolar ſyſtem. On the ſame ground alſo, cold is univerſally allowed to be a mere negative quality, and to mean nothing more than the abſence of heat or fire.

It appears the moſt convenient form of treating this important ſubject, firſt to conſider fire in its capacity of exciting heat and producing expanſion; and ſecondly, to direct our attention to the various phenomena which it exhibits in its combined ſtate, as the efficient cauſe of fluidity both in the incompreſſible and elaſtic or aerial fluids. I ſhall firſt enter into a brief detail of the principal and known properties of fire, caloric, or heat; and ſhall afterwards illuſtrate theſe properties by its effects in different inſtances.

Firſt. The particles of *fire* appear to be more *minute* than thoſe of any other ſubſtance whatever. It penetrates all bodies with the utmoſt eaſe. If the pores of a body are diſpoſed in right lines, ſo as to admit the paſſage of fire without impeding its velocity, it will be tranſmitted in the ſtate of light as well as in its ordinary ſtate, when it excites the ſenſation of heat, as is the caſe with all tranſparent or diaphanous bodies. But there is no body, however denſe, which will not admit this element to circulate through its pores with the utmost rapidity. A piece of charcoal screwed up fast in a vessel of iron will be ignited as effectually as in the naked fire. Those bodies which most completely exclude the air, are utterly unable to resist the entrance of fire: for a thermometer will rise equally in the most complete vacuum that can be produced, as in the open air *.

2dly. The matter of fire is attracted more or less by all bodies. When any heated body comes in contact with a cold one, the former loses a part of its heat, and both of them become equally warm. If heated iron is laid upon a stone, its heat will flow into the stone; if thrown into water, the heat will be diffused through the water. If a number of different substances, as metals, wood, wool, &c. are brought together into a place where there is not a fire, if they are of different temperatures, that is, of different degrees of heat, the fire will be attracted from the hottest to those that are colder, till the perfect equilibrium is restored, or till they have all acquired the same temperature, as may be proved by applying the thermometer successively to each of them.

It does not appear, however, that all bodies have an equal attraction for the matter of fire. If a rod of iron is put into the fire for a short time, the end which is at a moderate distance from the fire will almost burn the hand; but a rod of wood, of the

* See Jones's Phys. Disq. p. 88.

same

fame length will be confumed to afhes at the end which is in the fire before the other end is fufficiently heated to burn the hand. A ball of lead and a ball of wool may be of exactly the fame temperature by the thermometer, but they will not appear of the fame degree of heat on applying the hand. If they are of a temperature below that of our bodies, the lead will appear much colder than the wool, becaufe it attracts the heat more rapidly from the hand; if they are of a higher temperature, the lead will appear much hotter, from the facility with which it parts with its heat. This property in bodies is called their *conducting* power; and thofe bodies through which the element of fire moft rapidly circulates, are called good conductors.

The power of conducting the matter of fire feems to depend upon the texture of bodies, that is, upon the contact of their parts*; hence the exceffive flownefs with which heat is communicated to bodies of a rare and fpongy texture. Thus flannel, wool, and feathers, are confidered as warm coverings, not becaufe they poffefs more heat in themfelves (for they ferve to preferve any cold body in a cool ftate better than other fubftances) but becaufe they prevent the efcape of the animal heat from our bodies. It is a well-known fact, that ice is generally

* This is proved by an eafy experiment:—If a cube and a fphere of the fame metal are put upon a plane intenfely heated, the heat will flow fafter into the cube; and if the fame bodies are previoufly heated, and expofed on a cold plane, the cube will cool fooneft.

§ kept

kept in ice-houſes in ſtraw or wool, thoſe ſubſtances, from the rarity of their parts, preventing the entrance of the heat. On the ſame principle the ground is kept warm by ſnow, that ſubſtance being of a ſoft and ſpongy texture. It is true it will not keep the ground warmer than the freezing point; but that is warm, when compared with the intenſe cold which is occaſionally experienced in moſt northern climates.

An ingenious and accurate experimentaliſt has lately endeavoured to eſtimate the conducting power of different bodies. The conducting power of mercury he found to be to that of water as 1,000 to 313. Hence it is plain why mercury appears ſo much hotter or ſo much colder to the touch than water, at a time when they are evidently of the ſame temperature by the thermometer. Common air is a much better conductor than the Torricellian vacuum*; its conducting power, compared with that of the vacuum, is nearly as 1,000 to 605.

A moiſt air conducts the matter of fire with much greater rapidity than a dry air; but the rarity or denſity of the air appears to have little effect upon its conducting power.

* Made by filling a tube, cloſed at the top, with mercury, and emptying the upper part of the tube by immerſing the lower in a veſſel filled with the ſame fluid, as is the caſe in the common barometers. This is the moſt perfect vacuum we can make.

The proportion of the conducting power in the different ſubſtances which were the objects of his experiments, is as follows:

Mercury	- - - - - - -	1,000
Moiſt air	- - - - - - -	330
Water	- - - - - - -	313
Common air, the barom. at 27 inc' 9 lines		$80\frac{41}{100}$
Rarified air, - barom. at 6 - 11 lines		$80\frac{23}{100}$
The ſame, - barom. at 1 - 2 -		78
The Torricellian vacuum	- - - -	55 *

From the different effects of bodies upon our feelings, according to their conducting powers, ariſes the diſtinction which philoſophers have made between abſolute and ſenſible heat. It will be remembered, that the ſenſation of *hot* is the entrance of fire or heat into our bodies, and the ſenſation of cold is its departure from them †. Theſe circumſtances render the ſenſes of animals a very inaccurate meaſure of heat; eſpecially if we conſider further, that much will alſo depend upon the ſtate of the organ of feeling at the particular time. Water, at the temperature of 62°, appears cold to a warm hand; but it will appear warm to a hand which is of a lower temperature ‡. Travellers, therefore,

* Sir Benj. Thompſon's (now Count Rumford) Experiments on Heat. Phil. Tranſ. vol. lxxvi.

† The ſudden and unexpected application of an extremely cold ſubſtance to the human body, produces a ſenſation very ſimilar to that of a hot one.

‡ Crawford on Animal Heat, p. 5. 2d edit.

from

from a warm to a cold country, will have fenfations very different from thofe who travel in an oppofite direction, fhould they happen to meet, as they frequently do, in a temperate climate. It is evident that the travellers from a cold climate; being deprived of lefs heat than ufual, will have the fenfation of warmth; and the others, on the contrary, will experience a degree of cold fufficient to excite confiderable uneafinefs.

3dly. The matter of fire will exift in a ftate of combination. I do not contend for the term chemical combination, in the ftrict and literal fenfe of the word; it is fufficient if it can be proved, that fire may exift in bodies in a *latent* ftate, or in a ftate not perceptible to our fenfes. It will be found by obfervation, that every body which exifts contains a quantity of the matter of fire in this fixed or neutralized ftate, difarmed of all its active, penetrating, and deftructive qualities, like an acid and an alkali in combination. If the coldeft bodies with which we are acquainted are condenfed or brought into a fmaller compafs, a quantity of fire will be emitted. If a piece of lead or iron is beaten with a hammer, or compreffed in a vice, fo as to force it to contract its dimenfions, it has been already remarked that a degree of fenfible heat will be produced.

Fluids, from their very nature and conftitution, contain a greater quantity of fire in a latent ftate than folid bodies: indeed it is now univerfally admitted, and may be eafily proved, that the fluidity of all bodies is altogether owing to the quantity of fire which they retain in this latent or combined ſtate, the elaſticity of which keeps their particles remote from each other, and prevents their fixing into a ſolid maſs. All bodies, therefore, in paſſing from a fluid to a ſolid ſtate, emit a quantity of fire or heat. When water is thrown upon quick-lime, it is abſorbed by the lime, and in this ſtate it is capable of retaining a much ſmaller quantity of fire than in its natural ſtate; on the ſlacking of lime therefore a very intenſe heat is produced, the fire which preſerved the water fluid being diſengaged and detached. If ſpirit of vitriol is added to ſtrong oil of turpentine, they will condenſe into a ſolid maſs, and a great quantity of heat will be ſenſibly emitted. If water is expoſed to freeze, and a thermometer applied to it, during the act of freezing, or paſſing from a fluid to a ſolid ſtate, it will be found ſeveral degrees warmer than the air which ſurrounds it, which is owing to the heat or fire emitted by that part of the water which is converted into ice. This effect is ſtill more apparent from the condenſation of the elaſtic fluids, which, from their rarity, contain a greater proportion of the matter of fire.

Upon the ſame principle it will be found, on the other hand, that when any body paſſes from a ſolid to a fluid ſtate, the adjacent bodies will be deprived of a quantity of their natural heat. Thus if a quantity of aqua-fortis is poured upon ſolid ice, the ice immediately liquifies, and an aſtoniſhing degree of cold is inſtantly produced, even by the fire-ſide: this effect is altogether owing to the quantity of of heat which is abſorbed by the congealed water reaſſuming its fluid form. This experiment will ſerve to explain the fact that a thaw is generally colder than the commencement of a froſt. The abſorption of the matter of fire is further exemplified in the inſtance of bodies paſſing from the ſtate of a common fluid to that of vapour, or an elaſtic fluid. If a thermometer is immerſed in ſpirit of wine, in water, or in any fluid that eaſily evaporates, and is afterwards taken out and ſuſpended in the air, the thermometer will ſink two or three degrees, though the temperature of the air and water ſhould be exactly the ſame: the fact is, the ſmall quantity of fluid which remains on the bulb of the thermometer is carried off in vapour, and in that caſe the mercury within the thermometer is deprived of a certain portion of its latent fire. If the thermometer is repeatedly dipped in the fluid, the cold which is produced will be conſiderable. If ether, which is a very volatile fluid, is applied to any part of our bodies, cold is immediately produced; and on the ſame principle, a man may be frozen to death in very warm weather, by expoſing him to continued evaporation; which may be effected by throwing repeatedly upon his body a quantity of ether, of ſpirits of wine, or of any other fluid which is eaſily evaporable. It is a common practice in China to cool wine or other liquors by wrapping the bottle in a wet cloth, and hanging it up in the ſun; the water in the cloth is gradually converted into vapour, to form which the liquor in the bottle is deprived of its latent fire. The celebrated Mufchenbroek was aftonifhed at the freezing of a wet cloth which was hung up to dry, when there was no appearance of froft in the atmofphere: the folution of the difficulty is, the temperature of the air at the time muft have been within fome degrees of froft, and the temperature of the cloth was fuddenly reduced to the freezing point by the lofs of a part of its heat from evaporation.

Let it be remembered, that in all thefe inftances there is an evident acceffion or increafe of the matter of fire thrown into the bodies which are rendered fluid, and yet the temperature or obvious heat of the fluids is not increafed, as may be proved by the thermometer; wherefore it is plain that the fire exifts in thefe fubftances in a *latent* or combined ftate.

4thly. The matter of fire is elaftic, as is proved evidently from all its effects. There is indeed reafon to believe that fire is the only fluid in nature which is permanently elaftic; and that it is the caufe of the elafticity of all fluids which are efteemed fo.

From the elafticity of this element it refults that all natural bodies can only retain a certain quantity of it, without undergoing an alteration in their ftate and form. Thus a moderate quantity of fire admitted into a folid body expands it; a ftill larger quantity renders it fluid; and if the quantity is ftill increafed, it will be converted into vapour. But this, and all the other properties of fire, will be better

underftood

underſtood from its effects. Let it ſuffice to remark for the preſent, that moſt fluids may be converted into a ſtate of unuſual rarity, by the acceſſion of fire. Vapour is 1800 times leſs denſe than water; and thoſe matters which have a ſtronger attraction for fire may by the ſame means be converted into fluids permanently elaſtic. The nitrous acid is wholly convertible into two ſpecies of air, oxygen and azote, or pure and phlogiſticated air; and oils, reſins, charcoal, and other inflammable matters, will by the application of heat readily aſſume the form of inflammable air.

Chap. III.

OF EXPANSION.

Experiments proving the expanſive Force of Fire, or Caloric.—Inſtruments for meaſuring Degrees of Heat.—Thermometers.—Dr. Black's Mode of meaſuring high Degrees of Heat.—Mr. Wedgwood's.

FIRE, as was intimated in the preceding chapter, expands all bodies which it penetrates, more or leſs, in proportion to its quantity, and to the nature of thoſe bodies. The expanſion of water, even previous to its aſſuming the form of vapour, may be ſeen in an eaſy experiment. If a quantity of cold water, contained in a clear flaſk, is immerſed in a veſſel of boiling water; as the heat enters, the water in the flaſk will be ſeen to riſe in the neck till it overflows.

An iron rod a foot long being heated red hot, became $\frac{1}{70}$th longer than before; and a glaſs cylinder, a fathom long, under the ſame circumſtances, gained $\frac{1}{70}$th in length. A metalline ring thus heated was increaſed $\frac{2}{100}$ in its diameter: and a glaſs globe became extended $\frac{1}{100}$ part by the heat of the hand only applied to its ſurface *.

* Boerhaave's Chem. by Shaw, Vol. I. p. 299.

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It is a well-known practice to immerſe razors, or any inſtruments which are required to cut ſmooth, in warm water; as the whole of the metal expands, the edge is alſo proportionably expanded, and conſequently is rendered ſo much finer and ſmoother.

An inſtrument was invented by Mr. Jones, for meaſuring the force of expanſion, which by the flame of a farthing candle was able to lift a weight of five hundred pounds, without any aſſiſtance from the mechanical powers; and he ſhews that the ſame inſignificant power, namely, the flame of a ſmall candle, would by the force of expanſion overcome a weight even of five thouſand pounds, could an inſtrument be conveniently fitted up for the experiment *. Indeed, when we conſider that the force of coheſion in metals is ſo immenſe as to enable a gold wire of one-tenth of an inch diameter to ſupport five hundred pounds weight, and an iron wire of the ſame dimenſions to ſupport one thouſand five hundred pounds, without producing any ſeparation of the parts; what muſt be the force of fire, which can relax and even diſſolve the texture of the firmeſt metals †?

It is a fact univerſally known, that clocks and time-pieces in general go ſlower in warm weather, and faſter in cold; this effect is owing entirely to the expanſion of the pendulum, which being lengthened by the acceſſion of heat or fire in warm weather, makes a longer vibration, and conſequently loſes a proportionate quantity of time; on

* Jones's Phyſ. Diſq. p. 99, 100.

† Ib. p. 98.

the

the contrary, the length of the pendulum being contracted by cold, the vibrations will be proportionably quicker, though the quantity of time gained or loſt in a ſingle vibration may be exceedingly trifling; yet as the vibrations are very often repeated, the effect will in a courſe of time be very conſiderable. An alteration of one hundred thouſandth part in the time of a ſingle vibration, will amount to nearly that of a whole vibration in the courſe of a day *.

The caſes are ſo numerous in philoſophy and the arts, when it is deſirable to be informed of the quantity of heat which exiſts in bodies, that it ſoon became an object of the utmoſt importance, to diſcover an accurate method for aſcertaining it. The expanſive property of fire was the property which moſt naturally ſuggeſted itſelf as likely to furniſh an eaſy method of accompliſhing this object, ſince the evidence of our ſenſes aſſure us that, at leaſt in all lower degrees of temperature, the expanſion of bodies bears ſome degree of proportion to the quantity of the matter of fire which they have imbibed.

Air, as was intimated in a preceding chapter, was the firſt fluid which was employed as a meaſure of heat and cold. A ſmall tube was prepared, open at the top, into which a quantity of coloured liquor was introduced; a quantity of air was left in the lower part of the tube, below the liquor, and in propor-

* Jones's Phyſ. Diſq. p. 98.

tion

tion as this air expanded or contracted, the heat of the ſurrounding medium was ſuppoſed to be increaſed or diminiſhed. The manifeſt inconvenience attending this inſtrument was, that as the upper orifice of the tube was neceſſarily left open, it was liable to be affected by two cauſes, by the natural heat of the medium, and by the weight of the atmoſphere preſſing upon the liquor in the upper part of the tube.

The next fluid that was made uſe of was ſpirit of wine, and this, being incloſed in a tube which was exhauſted of air, afforded an inſtrument much more perfect than the former. The principal objection to this ſpecies of thermometer is, that ſpirit of wine is incapable of enduring any great degree either of heat or cold, ſince it boils in vacuo at fifty-two degrees. This thermometer is diſtinguiſhed by the name of the Florentine thermometer, as it was invented by ſome of the members of that academy. It was afterwards greatly improved by the celebrated M. Reaumur, who proportioned the expanſibility of the liquor to the ſize of his tube, by diluting it with water, or the contrary; the generality therefore of thermometers made with ſpirits of wine are termed Reaumur's thermometers.

Oil was employed by Sir Iſaac Newton inſtead of ſpirit of wine, as being capable of a greater degree of expanſion, ſince that fluid will bear about four times the heat of boiling water before it boils, and in general a very great degree of cold is required to make it freeze. The principal objection to Newton's ton's thermometer arifes from the vifcidity of the oil, which occafions it to adhere to the fides of the veffel, fo that a confiderable quantity of the fluid being retained by the glafs, when the thermometer finks it appears to fink lower at firft than it ought to do, according to the natural temperature.

Thefe thermometers, therefore, were all of them fuperfeded by the famous invention of Olaus Roemur, improved by Farenheit, who fubftituted mercury inftead of the other fluids. Mercury is found to be a more homogeneous body than any other fluid, and more regular in its expanfions, befides that it is capable of exhibiting a more copious fcale of both heat and cold.

Sir Ifaac Newton, obferving that water uniformly froze with a certain degree of cold, and as uniformly boiled when the heat was increafed to a certain degree, took what is called the freezing point for the commencement of his fcale, and from that to the boiling point he counted thirty-four degrees, and divided his fcale accordingly. It is evident, however, that even in this climate we have many degrees of cold below the freezing point. Reaumur, therefore, though he commenced his fcale alfo at the freezing point, yet admits of feveral degrees below it, and proceeds both ways from 0; the boiling point in his fcale is at 80° above 0. The fcale of Farenheit begins confiderably below the freezing point, at that period of cold which is produced by furrounding the bulb of the thermometer with a mixture of fnow or pounded ice and fal ammoniac or fea-falt: he divided

vided his ſcale into minuter portions than either Newton or Reaumur, on which account it is well known that the boiling point in Farenheit's thermometer is at 212°. Sir Iſaac Newton's thermometer is, I believe, now quite obſolete: Reaumur's is ſtill uſed by many of the French, and other experimentaliſts. The degree of heat, however, when noted on either of theſe inſtruments, may eaſily be computed, by remembering that 34° of Newton's anſwer to 80 of Reaumur, and to 212 of Farenheit; and that the freezing point, which is the commencement of both the other ſcales, is in Farenheit's at 32° above 0.

The graduating a mercurial, or Farenheit's thermometer, cannot, from what has been obſerved, be a difficult taſk. The mercury muſt be carefully purged from air, as that, being a more elaſtic fluid, would create ſome irregularity in the expanſions of the metal, or would collect in the upper part of the tube, which ought to be the moſt perfect vacuum that can be formed. It is well known that what is called the *Torricellian** vacuum is formed by filling a glaſs tube with mercury, and then inverting the tube in a veſſel of the ſame fluid, and withdrawing it ſlowly till the mercury ſubſides, by which means all that part of the tube which is above the mercury will be free from air; on withdrawing the tube out of the mercury, it is obvious that the orifice muſt be ſtopped with the finger or ſome other ſtopper, to prevent the air from ruſhing in. When by theſe

* From Torricelli, the inventor.

means

means a quantity of mercury is included in a glass tube with a small bulb, the glass may be easily closed by applying an ignited charcoal and a blow-pipe, such as the jewellers make use of, which melts the glass, and enables us to twist it round, in such a manner as completely to close it against the admission of air; and this operation is called *hermetically* sealing it *. In order to graduate the thermometer, it must be first immersed in a mixture of pounded ice or snow and sal ammoniac, and the point at which the mercury settles must be marked as the commencement of the scale, or 0. It is next to be immersed in boiling water, and that point is to be marked 212°, and the intermediate part of the thermometer must be divided into this number of degrees.

Thermometers with small bulbs, and proportionable cylinders, are most useful, since a large volume of mercury requires a considerable time to heat and cool. It is also accounted a favourable circumstance when that part of the bulb which is adjoining to the tube is rather of a conical form.

That the thermometer is a true measure of heat, is proved by some very satisfactory experiments. If equal quantities of hot and cold water are mixed together, the heat of the mixture will be nearly as

* It is easy to prove whether the tube is a perfect vacuum or not, after it is hermetically sealed, by merely inverting it, and observing whether any bubble of air remains to resist the mercury's falling to the bottom of the tube.

§ the

the mean heat of the two component parts *. This fact was ascertained by a still more accurate experiment of Dr. Crawford, who contrived a method of combining the boiling and freezing points together, and found that the degree of heat communicated to the thermometer was as nearly as possible the arithmetical mean †.

It is evident, from the nature of expansion, that thermometers might be constructed of solid bodies. Metallic thermometers have indeed occasionally been made, and graduated for different purposes; but their utility is necessarily very limited, since solid bodies are expanded with much more difficulty, and in a less degree, than fluids.

Though the mercurial thermometer is so much more perfect, and is capable of exhibiting much higher degrees of heat than those which had been in use before the time of Farenheit; yet as mercury boils at 600°, that is, considerably below the red heat of iron, and as it is plain that no fluid can afford any true measure of heat beyond that point in which it is itself converted into vapour, it is equally plain, that there must exist several degrees of heat which cannot possibly be exhibited by the mercurial thermometer. These degrees are very

* This experiment was originally made by Dr. Brook Taylor. It was afterwards repeated by M. de Luc, and by Dr. Crawford; who, from the impossibility of conducting the experiment without loss of time, found the heat of the mixture always below the arithmetical mean.

Crawford on Heat, p. 18, *et seq.* 2*d edit.*

† Ib. 47, 48.

inaccurately

inaccurately defined by the chemiſts and artiſts, according to the appearance, terming them a *red* and *white* heat, &c. To remedy the inconveniences reſulting from the want of a definite ſtandard of heat above the point of boiling mercury, ſeveral methods have been propoſed, but there are only two which I eſteem worthy of notice.

A very eminent philoſopher, who may be termed the father of the modern doctrines concerning heat, propoſes, in order to aſcertain the heat of any given furnace, for inſtance, to heat ſome body (the dimenſions of which may be eaſily taken) in that furnace, and when heated to plunge it into a quantity of cold water, and multiply the degree of heat by the proportion which the bulk of the water bears to that of the body heated. Thus, if a piece of iron is taken *red hot*, and thrown into a quantity of water 100 times its bulk, when the heat which was concentrated in the iron is diffuſed through the whole quantity of water, it is evident that the temperature of the water thus heated, multiplied by 100, will give the heat of the iron when red hot.

Another mode of aſcertaining high degrees of heat has been propoſed by the late Mr. Wedgwood, who by means of a diſtinguiſhing property in argillaceous bodies, namely, that of contracting when expoſed to fire, was enabled to conſtruct a new thermometer for this purpoſe. The ſenſible contraction of earthen-ware commences at a low red heat, and proceeds regularly till the clay becomes vitrified. Mr. Wedgwood's thermometer, therefore,

fore, consists of a small portion of this clay, properly baked, and so nicely adapted to a brass gage, that the clay is permitted to slide along the gage in proportion as it is contracted by the fire. He divided his scale, from the degree of heat at which the clay begins to contract, to the greatest degree of heat he was able to produce, into 160°. By this instrument he found, that copper melted at 27°; silver at 28°; gold at 32°; cast iron at 130°.

Chap. IV.

OF FLUIDITY.

Caloric equally the Cause of Expansion and Fluidity.—Phenomena of Bodies passing from a solid to a fluid State, and the contrary.—Intense Cold of the Southern Hemisphere explained.—Distinction between Expansion and Fluidity.—Experiments illustrative of the Doctrine of latent Heat.

IT was intimated that all bodies are capable of containing only a limited quantity of fire, without undergoing an alteration in their external form; the same cause which produces expansion, being increased to a certain degree, produces a total dissolution of the parts of bodies, and reduces them to a fluid state; and a further increase of the same power renders them volatile, or causes them to be carried off in the form of an elastic fluid, such as air or vapour.

After what has been formerly stated, it will be no difficult matter to conceive the cause of all these effects to be the same. The subtile matter of fire, which appears to be the only substance in nature which is permanently elastic, or between whose particles a natural repulsion exists, insinuating itself between the particles of bodies, destroys or rather counteracts the natural power of attraction or cohesion, which impels the particles of bodies to approach as nearly in contact to each other as possible. When a body is reduced from a solid to a fluid state, a quantity of heat or fire is absorbed from some of the surrounding media. The nature of fluids would therefore be, perhaps, not improperly described, by supposing them to consist of the very minute particles of the bodies from which they are produced kept floating in a quantity of fire. To understand how fire may exist in this combined state, without exhibiting any of its destructive properties, let it be remembered, that fire, like every other body, can be only active while in a disengaged state. Fire cannot excite in our organs the sensation of heat, unless it penetrates those organs; if therefore it is retained by another body by the force of a superior attraction, it is evident it cannot affect our organs as it would if in a state to be attracted by them. In the same manner the mineral acids (aqua-fortis for instance) in a disengaged state act with violence on almost every substance, and corrode or ulcerate our flesh, when brought in contact with them; but if united with a body which possesses a stronger attraction for them (such as an alkali) they will not leave that body to act upon any other, but are perfectly disarmed of all their noxious qualities: thus the safe and innocent compound salt-petre is formed from two violently active and corrosive substances, a caustic alkali, and the nitrous acid, or aqua-fortis; and common salt from the same alkali, and the muriatic acid.

Every body in paſſing from a ſolid to a fluid ſtate, or from that of a common to a rarer or elaſtic fluid, abſorbs a quantity of caloric or fire, and conſequently a degree of cold is always produced by the proceſs; and on the contrary, every body in paſſing from a fluid to a ſolid ſtate, or from that of a rarer to that of a denſer fluid, emits a quantity of that fire which kept it in a ſtate of fluidity; and by this proceſs, on the other hand, a proportionable degree of ſenſible heat is produced.

A number of phenomena, which were before unexplained, are now clearly illuſtrated by this theory. What is called the freezing mixture, it is well known conſiſts of a quantity of pounded ice or ſnow with aqua-fortis, or any ſaline ſubſtance. The immenſe cold which is ſuddenly produced by this proceſs, is owing entirely to the ſudden liquefaction of the ice, in which caſe all the adjacent bodies muſt ſupply a quantity of caloric or fire, which is abſorbed by the melting ice, and retained by the fluid in a latent ſtate, or ſtate of combination. Cold is produced by evaporation, on the ſame principle, the quantity of elementary fire which is attracted by a fluid when paſſing into a rarer ſtate, and which is required to form atmoſpheres of fire round the particles of the body, ſo as to keep them ſuſpended in the fluid form, is neceſſarily ſupplied from the ſurrounding bodies, and muſt be attended with a degree of cold.

The ſouthern hemiſphere is remarkably colder than that of the north, and even in the midſt of ſummer

ſummer an exceſſive degree of cold has been found in the regions which lie near the antarctic circle. To account for theſe phenomena, we muſt probably have recourſe to two cauſes. As there is a greater extent of water in that hemiſphere, the evaporation is conſiderably greater than in that of the north; and as the ſouthern ocean abounds with a multitude of immenſe ice iſlands, the continual melting of the ice abſorbs the matter of fire from all the circumjacent atmoſphere; and in fact we are informed by mariners, that the cold is conſiderably increaſed by the approach of one of theſe floating mountains of ice. Partly for the ſame reaſon a thaw is obſerved to be much colder than a ſettled froſt; though it is alſo to be remembered, that the atmoſphere is always rather inclined to damp in a thaw, and a damp air is a much more powerful conductor of heat than a dry one.

On the contrary, when a fluid body paſſes into a ſolid ſtate, a quantity of fire is neceſſarily extricated. The heat produced by ſlacking lime has ſometimes been ſo great as to fire wood; in this caſe it has already been ſhewn, that the component particles of the water being abſorbed by the lime, the fire which held it in fuſion is expelled. A mixture of the eſſential oils with ſpirit of vitriol produces the ſame effect; the mixture forms itſelf into a ſolid maſs, and the fire which the fluids contained is ſuddenly extricated. A quantity of water will often continue fluid at ſome degrees below the freezing point, but by agitating the water it forms ſuddenly into ice, and the fire which the fluid contained being ſet free, the thermometer will riſe ſome degrees. The air is often obſerved to be peculiarly mild during a fall of ſnow; the reaſon is, that the caloric which the water of the ſnow contained is diſcharged by its paſſing into a ſolid ſtate, and ſenſible heat is produced. The union of a cauſtic alkali, which contains no fixed air, with an acid, excites great heat, in the ſame manner as when water is thrown upon quick-lime; but if the alkali is mild, that is, if it contains a quantity of fixed air, that ſubſtance going off in an aerial form abſorbs the matter of fire, which it carries off with it, and no heat is generated *.

It was ſtated, that expanſion and fluidity are produced by the ſame cauſe: there is, however, this difference in the effects, that in expanſion there is a regular increaſe or extenſion of bulk, according to the degree of heat; whereas the tranſition from a fluid to a ſolid ſtate, or the contrary, is ſudden; and below or above a particular point of temperature, a body always remains fluid or ſolid. There are, it is true, ſome bodies which appear in an intermediate ſtate of fluidity, ſuch as wax, tallow, &c.; yet even in theſe the point at which they become fluid is a ſettled point, though the different ſtages of ſoftneſs depend upon the degrees of heat.

In expanſion alſo the ſenſible heat is increaſed in proportion to the effect; but it is different in fluidity;

* See Dr. Higgins's excellent Experiments and Obſervations, p. 319.

dity; for when bodies are arrived at the melting point, or point of fluidity, a large quantity of elementary fire is abſorbed, without producing any ſenſible heat, or altering the temperature of the body. This abſorption of the matter of fire frequently continues a conſiderable time, according to the ſupply from the adjacent bodies. Thus, when a thaw comes on, the heat is often far above the freezing point; and though the ice melts ſlowly, it is conſtantly ſurrounded by air warmer than itſelf, and conſtantly imbibing the matter of fire from it. On the other hand, if a quantity of boiling water is thrown upon ice, it will immediately melt; which proves that there is no difficulty in ſeparating the particles of ice, if a ſufficient quantity of heat is ſupplied: but the reaſon of theſe facts will be rendered clearer by the following experiments.

If a pound of water at 32° is mixed with an equal quantity of that fluid at 172°, the temperature of the mixture will be 102°, which is the arithmetical mean between the heat of the two fluids; but if a pound of ice at 32° is mixed with a pound of water at 172°, the temperature of the mixture will be 32°. Hence it appears, that in the melting of the ice one hundred and forty degrees of heat (that is, ſuch a quantity of elementary fire as is neceſſary to produce that heat) are abſorbed, or reduced to a ſtate of combination, ſo as not to produce any effect on the thermometer *.

* Crawford on Animal Heat, p. 72.

The heat which the water abſorbs in aſſuming its fluid form is again ſeparated by congelation. If a pound of water at 32° is mixed with an equal quantity of ice at 4°, nearly one-fifth of the water will be frozen, and the temperature of the mixture will be 32°. In this experiment the ice is raiſed from 4° to the freezing point. It is therefore evident, in this experiment, that by the congelation of one-fifth of the water a quantity of fire is emitted ſufficient to raiſe the heat of the ice nearly twenty-eight degrees; by the congelation therefore of a whole pound of water, a quantity of heat would be detached ſufficient to raiſe it five times twenty-eight degrees. The caloric which is extricated by the congelation of the water is therefore preciſely equal to that which is abſorbed by the melting of ice*.

There were diſputes, in the time of Farenheit, concerning the rarefaction of ice, whether it depended on the air contained in it during its fluidity. He imagined, that if he extracted the air from water, he could produce an ice heavier than water. He extracted the air therefore from ſmall glaſs globes filled with water. After expoſing them to an intenſe cold, they were a long time in freezing, though cooled greatly below the freezing point; but upon breaking them to examine them, the air ruſhed in, which, from the ſudden ſhock, occaſioned the water inſtantly to freeze. He afterwards found, that ſimple agitation would produce the ſame effect.

* Crawford on Animal Heat, p. 72.

If water which is freed from air, and which is perfectly at reſt, is expoſed to the atmoſphere when it is colder than 32°, it will frequently ſink eight or ten degrees below the freezing point, without undergoing any degree of congelation; but if the veſſel is ſlightly agitated, a portion of it will immediately become ſolid, and the mixture of ice and water will be raiſed to 32°. The reaſon of this increaſe of temperature in the remaining water will be evident from the preceding experiments. By the freezing of a part of the water, a quantity of elementary fire, which exiſted in the fluid, is expelled, by its aſſuming a ſolid form; and this fire, being diffuſed among the remaining water, raiſes its temperature to the freezing point.

Different degrees of heat are required to retain different bodies in a fluid form. Water, mercury, and ſome other ſubſtances, are kept fluid by a degree of heat conſiderably below the ordinary heat of the atmoſphere; and ſo great is the degree of cold which the latter endures, that, before the experiments of Profeſſor Braun, of Peterſburgh, it was not ſuppoſed that it was capable of being frozen.

CHAP.

Chap. V.

OF BOILING, VAPOUR, &c.

Elastic Fluids distinguished from common Fluids.—Specific Gravity of Vapour.—In what Manner Dr. Black was led to form his Theory of latent Heat.—Immense Force of Vapour.—Boiling.—All Fluids boil in a less Temperature in Vacuo, than under the Pressure of the Atmosphere.—Experiments.—Phenomena of Boiling and Evaporation explained.—Why Water extinguishes Flame.—Spontaneous Evaporation.—Phenomena of Dews, Mists, &c.

IF the matter of fire is accumulated to a certain degree, the substance which is exposed to its action will be converted from the state of a common fluid to that of an elastic or compressible fluid, generally transparent, and extremely rare and light.

Vapour or steam, which is water converted into an elastic fluid, is of a specific gravity one thousand eight hundred times lighter than water; that is, a given portion of water will, in an elastic form, occupy one thousand eight hundred times the space it did before. The process of passing from the state of a common fluid to that of vapour, is called boiling; and the degree of heat at which a fluid begins to boil is called the boiling point, which, in water, is fixed on Farenheit's scale at 212°.

When

When a fluid arrives at the boiling point, and paſſes from its ordinary ſtate to that of vapour, the ſame effect takes place as in the converſion of ſolid bodies into fluids, a quantity of caloric or elementary fire is abſorbed without any increaſe of temperature; and when an elaſtic fluid is condenſed, the ſame fire is conſtantly emitted, and ſenſible heat is conſequently produced. If we obſerve the heating of water, we ſhall find that the heat flows into it very faſt, till it arrives at the boiling or vaporific point. Suppoſe that in the laſt five minutes its heat is increaſed 10°, in the next five we ſhould expect that it would at leaſt be ſix or ſeven more; but this is not in reality the caſe, for though very little of the water is evaporated, yet the remainder is not ſenſibly hotter. In order to prove the time neceſſary to convert a quantity of water into vapour, a number of flat-bottomed cylindrical veſſels of iron were conſtructed, into which a quantity of water was put, at the temperature of 54°. The water was heated to the boiling point in four minutes, but it was not evaporated in leſs than twenty. Thus it is evident that the water had acquired 158° of heat in the ſpace of four minutes; and conſequently, as the heat of the fire continued the ſame, it required five times 158° of heat to convert it into vapour. This immenſe acceſſion of fire is, however, neither ſenſible in the water nor in the vapour, for if a thermometer is applied to the ſteam, it will not be found hotter than the boiling water, it is therefore really abſorbed by the fluid, which

which is converted into vapour, and is retained in the latter in a combined ſtate. When the vapour is condenſed in the refrigeratory of a ſtill, the latent or combined fire is once more rendered ſenſible, for the refrigeratory is heated much higher than the ſenſible heat of the vapour, as the heat, if accumulated, would raiſe the thermometer to more than 800°.

We are informed by Dr. Crawford, that Dr. Black, who is certainly the author of the preſent theory of heat and fluidity, 'was firſt led to the diſcovery of the abſorption of heat by aqueous vapour, in conſequence of an unexpected appearance which occurred in an experiment made with water at a high temperature. A quantity of that fluid having been raiſed in Papin's digeſter * to a temperature many degrees above the boiling point †, was ſuffered to communicate with the external air, by opening a ſtop-cock, upon which a part of it was inſtantly converted into vapour, and the water at the ſame moment ſunk to 212 ‡.' As it appeared however that only a very ſmall quantity of the water had been carried off by this ſudden evaporation, it was naturally concluded that the whole of the ſuperfluous fire which the water had previouſly imbibed was abſorbed by that part which aſſumed the form of vapour.

* Papin's digeſter is an iron veſſel, made particularly ſtrong.

† I have been told to 412.

‡ Crawford on Animal Heat, p. 77.

The

The fact is accounted as eſtabliſhed by the ſame philoſopher from the following experiment. If eight pounds of the filings of iron at 212 are mixed with a pound of water at 32, the temperature of the mixture will be nearly 122; the iron will be cooled 90 degrees, and the water heated 90. But if eight pounds of iron filings at 300 are mixed with a pound of water at the boiling point, the temperature of the mixture will continue at 212, and a part of the water will be ſuddenly carried off in vapour, which vapour itſelf will be found to retain the ſame temperature of 212. In this experiment the temperature of the iron is lowered 88 degrees, without any apparent acceſſion of heat to the water; the fair concluſion is therefore that the ſuperfluous fire is abſorbed and carried off by the vapour *.

Vapour is an elaſtic fluid, that is, it admits of being compreſſed within a compaſs proportioned to the force which compreſſes it. Its force in reſiſting compreſſion, when it is accumulated to a certain degree, is however greater than that of gunpowder, or of any power with which we are acquainted. Steam is therefore one of the moſt potent and moſt dangerous agents in nature. A ſmall quantity of water thrown upon boiling oil, or introduced among metals while in fuſion, produces the moſt formidable effects. The water ſinks towards the bottom in the oil, where being converted into vapour, by the force of its expanſion

* Crawford on Animal Heat, p. 78.

it

it cauſes a moſt violent ebullition and exploſion, and throws the heated fluid about with incredible velocity. Hence in caſting iron or copper veſſels, if the ſmalleſt particle of humidity is contained in the mold, or if the metal meets with any liquid in its paſſage from the furnace to the mold, it will be exploded with the utmoſt hazard to the workmen from the burning metal. We have an inſtance recorded in the Philoſophical Tranſactions, of the burſting of one of Papin's digeſters containing a pint of water, which demonſtrates the amazing expanſive force of vapour. The report on the burſting of the veſſel was heard at a conſiderable diſtance by a maid ſervant who was milking the cows in an adjacent field, and the ſervants within ſaid it ſhook the houſe; the veſſel flew in a direct line acroſs the room, and ſhivered an inch plank of oak in pieces: what is moſt extraordinary, no traces of water were to be found in any part of the room; the fire was however completely extinguiſhed *.

The force of the common ſteam-engine is well known †; and an inſtance recorded by Mr. Jones in his Phyſiological Diſquiſitions, ſerves well to mark its

* Phil. Tr. Abr. vol. viii. p. 465.

† In theſe machines, the ſteam is conveyed into a large cylinder or barrel of iron, in which a very heavy piſton of the ſame metal is raiſed: when the piſton is to fall, the ſteam is ſuddenly made to collapſe by the injection of ſome cold water, which immediately condenſes it, and makes a vacuum, ſo that the piſton is forced down again by the preſſure of the atmoſphere. By theſe alternate

its effects. ‘ A workman, who with ſome others was employed to repair a fire-engine at Chelſea, informed me, that as they were buſy about it in working it to underſtand the defect, the barrel, which was of great capacity, and too much worn with long uſe, burſt on a ſudden, and a cloud of ſteam ruſhing out at the fracture ſtruck one of the workmen who was ſtanding by, and killed him in a moment like a blaſt of lightning. His fellows ran up as ſoon as they could to give him aſſiſtance, but when they endeavoured to take off his cloaths, the fleſh came away from the bones along with them.’

Though all fluids are rendered elaſtic by fire, yet the quantity of fire neceſſary to raiſe them to a ſtate of vapour depends upon different circumſtances. The very nature of an elaſtic fluid renders it particularly liable to be affected by the weight which is incumbent upon it. All fluids therefore boil with a much leſs degree of heat in vacuo, than under the ordinary preſſure of the atmoſphere. Thus water moderately heated, and placed in the receiver of an air-pump, may be made to boil by withdrawing a part of the air by which it is compreſſed; and it will be obſerved to ceaſe as ſoon as the air is re-

nate riſings and fallings of the piſton, ſeveral of which are performed in the ſpace of a minute, the machine acts on the work of a forcing pump, by which the water is raiſed, and diſcharged at the proper place. This machine, conſidering the vaſt force of it, is one of the ſimpleſt in the world; but, like the digeſter, may become extremely dangerous if the fire by any accident ſhould get the power over it.

turned,

turned, and the preſſure reſtored *. In the moſt perfect vacuum that we are able to procure water boils at 90, and ſpirit of wine at 52, that is at 122 below the boiling point under the common preſſure of the atmoſphere.

A pleaſing experiment is related by that elegant and ingenious philoſopher, the preſent Biſhop of Landaff, which is illuſtrative of the nature of boiling in general, and particularly of what has been juſt advanced. With an intention of exhibiting a ſtriking inſtance of the increaſe of dimenſions produced by heat in fluids, he took a glaſs veſſel, not unlike a thermometer in form; the bulb contained above a gallon, the ſtem had a ſmall diameter, and was about two feet in length. This veſſel be filled with boiling water to the very top of the ſtem, and corked it cloſe with a common cork. The water and the cork were at firſt contiguous, but as the water cooled it contracted, and ſunk viſibly in the ſtem; and thus the firſt intention of the experiment was anſwered. But here an unexpected phenomenon preſented itſelf. The water, though it was removed from the fire, though it was growing cold, and had for ſome time entirely ceaſed from boiling, began to *boil* very violently. When a hot iron was applied to that part of the ſtem, through which the water in contracting itſelf had deſcended, the ebullition preſently ceaſed; it was renewed when the iron was removed; and it became more than ordinarily

* Higgins's Experiments and Obſervations, p. 313.

violent,

violent, when by the application of a cloth dipped in cold water that part was cooled. To account for these appearances, it is only necessary to recollect that by the sinking of the water in the stem a kind of vacuum is left between its surface and the cork; the water therefore necessarily boils with a lower degree of heat than it would under the pressure of the atmosphere. The space between the cork and the water is not however a perfect vacuum; it is occupied either by the vapour of the water, or by a small portion of air, or by both. Heat increases the elasticity both of air and vapour and thus augments the pressure upon the surface of the water, hence the ebullition ceases upon the application of the hot iron. Cold, on the contrary, diminishes the elasticity of the air, and condenses vapour; and thus the pressure upon the surface being lessened by the application of a cold cloth, the ebullition of the water became more violent. The heat of the water when it ceased boiling was 130° *.

An experiment of another distinguished philosopher affords perhaps a better illustration of the whole theory which has been just advanced. This gentleman placed a quantity of vitriolic ether under the receiver of an air-pump, which was so contrived that he was able to let down a thermometer at pleasure, without admitting the external air. He no sooner began to extract the air, than the ether was thrown into a violent ebullition, at the same time

* Chem. Essays, vol. iii. p. 162.

its temperature funk furprizingly. When the ether was firft put in, its temperature was about 58°, but it became fo cold when boiling, that a quantity of water in a veffel contiguous to it was fuddenly frozen. The manner in which thefe phenomena may be explained is this:—The weight of the atmofphere being removed, the heat which the ether contained was fufficient to make it boil. The elementary fire which the ether loft in boiling was difpofed of in forming a vapour more fubtile than the ether itfelf; which could not, confiftently with the principles eftablifhed, be formed without the abforption of a confiderable quantity of the matter of fire. Now as it appears that water and fpirit of wine boil in vacuo at 122° below their ordinary boiling point, it is natural that ether, which boils in the open air at about the heat of the human blood, fhould boil in vacuo at 24° below 0, a degree of cold fufficient to freeze any water that might happen to be in contact with the veffel which contains the ether.

As the weight of the atmofphere varies fome degrees at different times, it is evident, from thefe remarks, that the boiling point of fluids will alfo occafionally vary. Boerhaave fuppofes, that, according to the changes of the atmofphere, as marked by the barometer, the heat of boiling water may vary occafionally eight or nine degrees *;

* Boerhaave Chem. quoted by Watfon. Chem. Eff. vol. iii. p. 157.

and

and we find the opinion confirmed by the accurate experiments of M. de Luc and Sir George Shuckburg, in the courſe of which the boiling point was ſometimes lower than 205°, and ſometimes higher than 213° *.

Some of the phenomena of evaporation and boiling, not hitherto noticed, will receive a ſatisfactory explanation from this theory.—1ſt, If a ſingle drop of water is heated to the vapourific point, it is immediately converted into vapour; but if the quantity is more conſiderable, the phenomenon will be varied: for, if a quantity of water is thrown into an iron veſſel heated very hot, it will ſeem to run

* This will be better underſtood by exhibiting Mr. Cavallo's table of the reſult of each experiment.

Height of the Barometer.	Heat of boiling Water, according to	
	M. de Luc.	Sir G. Shuckburg.
	Parts of a Deg. deg.	Parts of a Deg. deg.
26	205,17	204,91
26½	206,07	205,82
27	206,96	206,73
27½	207,84	207,63
28	208,69	208,25
28½	209,55	209,41
29	210,38	210,28
29½	210,02	211,15
30	212	212
30½	212,79	221,85
31	213,57	213,69

Water boiling hot cools in ſix hours in the ordinary heat of the atmoſphere.

 about

about the vessel like quicksilver, but without touching the bottom or sides of the vessel. The reason is, that the water nearest the bottom and sides is converted into vapour, which prevents the fluid from coming in contact with the iron; and this is the reason also that a red-hot piece of iron dropped into water continues for some little time in the same red-hot state, the water nearest the iron being suddenly converted into an elastic vapour, which repels or keeps off the rest of the fluid.

2dly, The bubbling and hissing of boiling fluids, or of fluids upon the point of boiling, was unaccounted for till Dr. Black's theory elucidated the point. In the common mode of boiling water it is plain, that the bottom of the fluid arrives at the vapourific point of heat before the surface; a quantity therefore of the fluid which is nearest the bottom of the vessel is converted into vapour, which forcing its way through the superincumbent medium occasions that violent ebullion which always takes place when a fluid is heated to its vapourific point. The hissing of kettles and other vessels, previous to their arriving at the boiling point, is perhaps to be accounted for from these vapourific bubbles in their ascent meeting with the cold water, and discharging their fire, which condenses the vapour before it arrives at the surface, and occasions the feeble sound which has been just mentioned, without any considerable agitation of the fluid, or emission of steam.

3dly, The

3dly, The reafon why water, either hot or cold, immediately extinguifhes flame, will eafily be underftood from what has been premifed. When a quantity of water is thrown upon an ignited body, it is immediately converted into vapour, and this procefs fuddenly deprives the burning body of as much elementary fire as the vapour is naturally difpofed to abforb. If therefore the water is applied in fufficient quantity, the whole of the fire will be imbibed by the evaporation, and the body will be left totally deftitute of heat. For the fame reafon it is evident, that water will prevent the melting of metals, or of any fubftances which require a degree of heat fuperior to the boiling point, to render them fluid: for the water, being in contact with the other fubftance, will not permit its temperature to increafe, and all the fuperfluous fire which would heat it above the boiling point, if the water was not there, is carried off by the evaporation of that fluid *.

The

* Perhaps it may not be quite unacceptable to the reader to notice in this place the vulgar paradox: "That when water is boiling in a veffel, the bottom is cool; but the moment it ceafes to boil, the bottom becomes hotter." The whole of the paradox appears to be founded on an error of the fenfe. When a perfon applies his finger to the veffel, though he applies it for a confiderable time, it is not heated more than he can endure, for the blood in the courfe of its circulation lofes fome of its heat before it arrives at the extremities; and till the blood in the extremities is heated to the fame degree with that of the heart we feel no pain from burning; but as foon as this is effected, the leaft degree of heat becomes painful. When the finger is firft applied to the bottom of the veffel after it is taken

 off

The general proceſs which bodies not highly inflammable undergo when ſubjected to the action of fire, is firſt to be reduced to a fluid ſtate, and then to a ſtate of vapour. There are, however, ſome bodies which are converted into vapour without at all aſſuming the fluid form, ſuch as camphor, ſal ammoniac, arſenic, &c. Theſe, when expoſed to fire, fly off in vapour, without being melted; which vapour, on condenſation, becomes a ſolid maſs again. Theſe ſubſtances may therefore be ſaid to have their vapourific point below that of their fluidity; and the reaſon of this appears to be, that their particles have a ſtronger attraction for the matter of fire than for each other. In fact, we find that theſe ſubſtances may be reduced to a fluid form by confining them in cloſe veſſels, where they may be forced to endure a greater degree of heat than under the preſſure of the atmoſphere. Camphor at leaſt has in this manner been rendered fluid; and there is no reaſon why ſal ammoniac, and all the volatile alkalies, might not be reduced to the ſame ſtate; but from the great elaſticity of the vapour, the proceſs has not been completed for fear of burſting the veſſels.

There are ſome bodies which have never hitherto been reduced to a ſtate of vapour. Thoſe

off the fire, the heat is endured for theſe reaſons. When the boiling ceaſes, it is natural to take the ſame finger (for having dirtied one, people ſeldom chuſe to take another) and that finger, being already heated almoſt as much as it could bear, now finds the heat at the bottom of the veſſel exquiſitely painful.

 earthy

earthy ſubſtances which have been rendered fluid, have never, by any degree of heat, been rendered volatile, and there are ſome earths which have never been even brought into fuſion. Some of the metals, particularly gold and ſilver, were thought formerly to be abſolutely fixed. Mr. Boyle expoſed a ſmall quantity of each for two months to the heat of a glaſs-houſe furnace, and at the end of that time he found them not altered; they have ſince, however, been compelled to emit very ſenſible vapours by the more intenſe heat of a burning-glaſs: and as the diamond itſelf has been ſubjected to evaporation, it is not improbable that by a ſufficient quantity of heat every other mineral ſubſtance might be fuſed and volatilized.

The vapour of water, and moſt other fluids, requiring a degree of heat above that of the atmoſphere to keep it in a volatile ſtate, is eaſily deprived of its ſuperfluous fire; and its particles being no longer kept aſunder by a ſuperior force, yield to the ordinary impulſe of attraction, and are condenſed into the ſtate of a common fluid. There are, however, permanently elaſtic fluids, which are maintained in their elaſtic ſtate by the ordinary heat of this earth; and theſe by analogy we may conclude are compoſed of particles which have a weak attraction for each other, and are therefore preſerved in this rare and volatile ſtate by a moderate portion of the matter of fire interpoſed between them: of this kind is the air we breathe, and ſome other fluids, of which I ſhall preſently have occaſion to treat *.

It would be improper to diſmiſs this ſubject, without offering a few remarks on that ſpecies of evaporation which is termed ſpontaneous, as I apprehend it not to be eſſentially different from that of which we have been treating. It is evident that a quantity of humidity is continually and inſenſibly emitted by every body which contains any principle of moiſture. If a glaſs of cold water, or any cold body, ſuch as ſmooth marble, is expoſed in a room when many people are aſſembled, its outſide will be covered with dew; the walls of churches and other buildings which have not conſtant fires are covered with moiſture in the ſame manner, and this moiſture in both caſes is produced by the cold body (the glaſs of water, the marble, or the wall) condenſing the vapour with which the air is charged from the breath and perſpiration of the company. Similar to this is the dew on the inſide of windows, which in cold weather is frequently frozen, and aſſumes the forms of leaves, of trees, and of the moſt beautiful moſſes.

Water cannot be expoſed in open veſſels without ſuffering a diminution of its bulk, and indeed in courſe of time the whole will be exhaled. The vapour however which is thus formed is not ſufficiently elaſtic to produce any of the common effects

* As the ordinary heat of our atmoſphere is ſufficient to keep water and ſome other ſubſtances fluid; ſo it ſerves to keep theſe bodies in a volatile ſtate.

of

of vapour; for water will remain in bottles corked up without forcing the corks; the vapour ſtagnating over the ſurface of the water, prevents a freſh quantity from riſing: indeed the mere force of gravitation would in general be ſufficient to counteract the force of this ſpontaneous evaporation, was it not that the wind carries off the quantity which is exhaled, which would otherwiſe be ſuſpended and ſtagnate over the fluid. This vapour, it is to be obſerved, proceeds always from the ſurface of bodies; and the greater the extent of ſurface, the more copious the exhalation: it is obſerved, therefore, to riſe more copiouſly from a graſſy plain, from the pores of a ſpunge, or from looſe earth, than from any ſingle ſurface; and it is always more or leſs in quantity, according to the temperature of the atmoſphere.

The quantity of vapour which is raiſed in this manner from the earth, has been eſtimated by a very ſimple yet apparently accurate experiment of the Biſhop of Llandaff. Having provided a large drinking glaſs, the area of the mouth of which was twenty ſquare inches, he placed it with its mouth downwards on a graſs plat which was mown cloſe. The ſun ſhone bright and hot, and there had been no rain for upwards of a month. When the glaſs had ſtood on the graſs plat one quarter of an hour, and had collected a quantity of condenſed vapour, he wiped its inſide with a piece of muſlin, the weight of which he had previouſly aſcertained, and as ſoon as the glaſs was wiped dry the muſlin was weighed. The

medium

medium increafe of weight from various experiments, between twelve and three o'clock, was fix grains in one quarter of an hour from twenty fquare inches of earth. At this rate of evaporation, it is eafy to fee that, computing at feven thoufand grains troy to one pint of water, and eight pints to a gallon, not lefs than one thoufand fix hundred gallons of water would be raifed from one acre of ground in twenty-four hours. It may well be fuppofed that the quantity will be ftill greater when the ground has been drenched with rain. In order to prove this, the fame judicious philofopher made two other experiments, one of them the day after the ground had been wetted by a thunder-fhower; and to afcertain the circumftances more exactly, he took the heat of the earth by a thermometer laid on the grafs, which in the firft experiment was 96°, when the evaporation was at the rate of one thoufand nine hundred and feventy-three gallons from an acre in twelve hours. The other experiment was made when there had been no rain for a week, and when the heat of the earth was 110°: this experiment gave after the rate of two thoufand eight hundred gallons from an acre in twelve hours; the earth was hotter than the air, being expofed to the reflexion of the fun's rays from a brick wall *.

It is the vapour which is exhaled in this manner from the earth which forms thofe mifts fo commonly obferved in marfhy grounds. If a hole is

* Watfon's Chem. Effays, vol. iii. Eff. 2.

broken

broken in ice, we may obſerve a miſt riſe from it; the water being warmer than the air, emits a vapour, which the cold condenſes and renders viſible. It is the ſame vapour which, when condenſed by the cold of the night, forms the dew which is obſerved in ſmall globules, like pearls, upon the leaves of plants *. When the weather has been intenſely cold, if a thaw ſuddenly comes on, the walls of houſes are all covered with dew; for theſe thawing winds, coming from a hotter part of the world, bring with them a quantity of vapour, which is condenſed by the cold ſubſtances, when it comes into a more northern climate.

* This beautiful appearance has not eſcaped the poets; the Hebrew poets in particular have made the beſt advantage of the beauties of nature. The following is Buchanan's paraphraſe of a part of the cxxxiii Pſalm.

"Ut aura ſuavis balſami, quum funditur
Aaronis in ſacrum caput,
Et imbre læto proluens barbam & ſinus
Limbum pererrat aureum:
Ut *ros*, tenella *gemmulis argentiis*
Pingens Sionis gramina;
Aut verna dulci inebrians uligine
Hermonis intonſi juga."

Sweet as the od'rous balſam pour'd
On Aaron's ſacred head;
Which o'er his beard and down his breaſt
A breathing fragrance ſhed.
As morning dew on Sion's mount
Beams forth a *ſilver ray*;
Or *ſtuds with gems* the verdant pomp
That Hermon's tops diſplay.

Various

Various theories have been proposed to account for the ascent of vapour. One of the most plausible is that which attributes it to the attraction of the air; but this theory is in a great measure destroyed, by the consideration that vapour will ascend in vacuo. The electric fire has also been called in to account for this phenomenon; but if the electric fire is no other than common fire, or some particular modification of it, there is no reason to believe that the spontaneous evaporation depends upon any other principle than that which has been already stated as the cause of the formation of common vapour from boiling water.

The fact appears to be, that there exists such an attraction between the particles of fire and those of water, that whenever a portion of the former in a disengaged state meets with any of the latter, they immediately unite. Hence, when water is heated beyond the temperature of the atmosphere, it naturally yields up a quantity of its superfluous fire to restore the equilibrium, and this fire always carries with it a quantity of the fluid medium in the form of vapour. When these vapours first ascend, they are in an invisible state; and they must be in some degree condensed to enable them to reflect the solar rays, so as to become visible. This frequently takes place when they reach the higher and colder regions of the atmosphere, or if they happen to meet with cold winds in their progress thither: they then appear to us in the form of clouds. A still greater degree of condensation renders them too heavy to be be ſupported by the atmoſphere, and they fall down in the form of rain, ſnow, or hail, according to the circumſtances of their diſſolution.

Agreeable to this theory is the common obſervation, that in very cold weather vapour becomes viſible almoſt as ſoon as it is formed; thus in froſt the breath, which is vapour from the lungs, is always viſible. M. de Maupertuis ſaw in Lapland the warm vapour of a room converted into ſnow upon opening the door to the external air; and in a crowded aſſembly at Peterſburgh, the company ſuffering from the cloſeneſs of the room, a gentleman broke a window for relief; the conſequence of which was, that the cold air ruſhing in, cauſed a viſible circumagitation of a white ſnowy ſubſtance *.

Agreeably alſo to the ſame principles it is evident that air is a fluid which has a ſtronger attraction for the matter of fire than water, but that by means of this inſenſible evaporation the interſtices of the air, if I may ſo expreſs myſelf, are filled with a quantity of vapour, which being extremely rare, and being equally diffuſed, is inviſible to us. If, however, a ſtream of cold air is introduced from any quarter, the caloric, which is united with the water in the form of vapour, will flow into the cold air to reſtore the equilibrium, and the vapour will be condenſed. The condenſation will ſometimes be only

* Edin. Phil. Tr. Vol. I. p. 48.

"Like words congeal'd in northern air."

Hudibras.

ſufficient

ſufficient to produce the appearance of clouds, but at ſome times it will be ſufficient to cauſe rain, which will fall in greater or leſſer quantities, in proportion to the quantity of moiſture in the atmoſphere, and the degree of cold in the condenſing medium.

CHAP.

CHAP. VI.

OF IGNITION AND COMBUSTION.

Ignition, what; how produced.—Burning of Phosphorus.—Inflammable Air.—Culinary Fires.—Lamps, &c.—Why Flame ascends.—Theory of Argand's Lamp.—Best Form of Grates, Stoves, &c.—Combustion produced by some Substances without a Communication with the Atmosphere.—Gun-powder, &c.—Iron made to burn like a Candle.—Spontaneous Ignition.—Curious Facts.—Quantity of Heat excited in fusing different Bodies.—Scale of Heat.

IGNITION is that ſtate of bodies in which the matter of fire or caloric is rendered active, and obvious to the ſight, by the emiſſion of light; in other words, when both light and heat are at once emitted by any body, it is ſaid to be ignited. Ignition does not imply combuſtion, as the latter indicates a change or diſſolution of texture in the inflammable body; whereas ſome of the metals, and many of the earths, may be ignited without being conſumed.—But this is a ſubject which it will be neceſſary to treat more at large when I come to ſpeak of inflammable ſubſtances.

In all caſes of ignition or inflammation the matter of fire is detached from ſome body in which it previouſly exiſted in a latent ſtate. The ſubſtance with which fire is moſt copiouſly combined, and from

from which it is moſt eaſily detached, is *air.* If therefore any ſubſtance can be found in nature which has a greater attraction for the baſe of air than that has for the matter of fire, the union of theſe two ſubſtances will detach a quantity of the fire which had exiſted in a latent or combined ſtate; and ignition, and combuſtion, will be produced. Of this nature is the matter of phoſphorus, and that very common or almoſt univerſal ſubſtance, which is diſtinguiſhed by the name of hydrogen, or inflammable air. Thus if a quantity of phoſphorus is expoſed to the atmoſphere, it will abſorb a conſiderable quantity of the pure part of the air, and by the union be converted into phoſphoric acid. In the mean time the fire will be detached from the air; and, provided the air is well charged with heat, ignition or accenſion will be produced on the ſurface of the phoſphorus. Inflammable air (or bodies containing that principle) has, however, either a weaker attraction for air than phoſphorus has, or its particles have a ſtronger attraction for each other. It is neceſſary therefore that it ſhould be preſented to the air in a rarer ſtate; and a degree of internal agitation, and even a third attractive power, are required to effect the union of the two ſubſtances, and the detaching of the fire from them. Thus, for inſtance, if pure air is mixed with a quantity of inflammable air, the electric ſpark, or a ſmall quantity of fire in ſome form or other, muſt be introduced to effect their accenſion. In this caſe a double attraction takes

2 place.

place. The pure and inflammable airs unite together, or are condenfed into a fluid, and the matter of fire, which is introduced, carries with it the fire which is detached from the two airs, and thus a complete ignition is produced. In the ordinary procefs of burning, when a quantity of inflammable or combuftible fubftances are heaped together, and fire introduced among them, by the action of the fire the inflammable part is firft expanded from its folid ftate into a ftate of inflammable vapour or air, it comes neceffarily into contact with the pure air of the atmofphere, and the action of the fire ftill continuing, the matter of fire is detached from the air, and combuftion enfues in the fame manner as in the former cafe, when the pure and inflammable airs are fired by the electric fpark.

Hence there can be no combuftion without a fupply of pure air; and from this confideration moft of the phenomena of combuftion may be explained. In a common coal fire, if the coals cake or adhere in fuch a manner that the inflammable part cannot come in contact with the external air, the fire is neceffarily extinguifhed. Flame is ignited vapour; but as that part only which comes in contact with the air can be ignited, that part of the inflammable vapour, which is not confumed, takes the form of fmoke and foot, and adheres to the fide or top of the place or veffel which contains the fire. The flame of a common lamp or candle may be confidered as a tube of fire, in the hollow of which the inflammable vapour is inclosed. It assumes a conical form, in consequence of the gradual consumption of the vapour, which is lessened in quantity as it rises, and consequently is contracted in its dimensions. A considerable quantity of the vapour, however, still escapes in the form of smoke, as must be evident to any observer, and as is decidedly evinced by holding a paper, or any other covering, over the flame, in which case a quantity of soot will presently be collected.

If these principles are clearly understood, it will no longer be a subject of wonder that all flame naturally ascends. Vapour is considerably lighter than air, and flame is no other than ignited vapour. Thus in lighting a common lamp or candle at an ignited bar of iron, or any other burning body, the wick of the candle must be applied to the lower surface of the ignited body, and not held above it, because then the vapour, which the heat extracts from the candle, comes in contact with the burning body, and accension takes place. It sometimes indeed may happen, that the lamp or candle may be lighted by holding it above the ignited bar; but it is obvious, in that case, that a quantity of the oil or tallow first drops on the burning body, and is then converted into vapour and flame, so that at the time of the accension taking place, the wick is actually surrounded with flame, above as well as below.

To remedy the immense waste of oil, which, according to the common construction of lamps, was disposed of, unconsumed, in the form of smoke and

and foot, was the great object of that very ingenious invention, the patent lamp of M. Argand. I recollect, some years previous to M. Argand's invention, I turned my attention to the procuring of a vivid flame, without a waste of oil, or the offensiveness of smoke. I observed that, the smaller the wick of a lamp, the brighter in general was the flame, and for this plain reason, that in these cases a greater surface than usual, proportionably to the quantity of vapour, was exposed to the air. My scheme was, therefore, to procure a lamp with a number of very small wicks, between each of which there was to have been an orifice or chimney, which might introduce a current of air, and keep the flame proceeding from each wick distinct. M. Argand's, I must confess, is a great improvement upon this idea. By means of a thin circular wick, through the middle of which a current of air is introduced by a funnel, he produces a very thin flame, and consequently exposes a very large surface of the oily vapour to the contact of the air. As there is, however, a strong attraction between the particles of fire, there would be danger of the flame uniting from all the sides of the lamp, at a certain height above the funnel, and so forming a conical flame like that of a common candle, was it not that this effect is prevented by a tube of glass, with which he surrounds the flame, which, when warmed, counteracts the attraction, which the different sides of the circular flame would have for each other, and so preserves the current of air free, and without interruption.

The same principles will apply to the construction of common fires. The great object should be, to expose as large a surface of the fuel as possible to the air, or rather, if possible, to introduce a strong and diffused current of air through the fire. On this principle the air furnace is constructed. It is well known that these furnaces consist of an aperture or ash-hole under the fire, and a high vent, funnel, or chimney above, and that the door, by which the fuel is introduced, is kept closed, unless it should be occasionally opened for the purpose of diminishing the heat. By means, therefore, of the high vent or funnel, the air above is rarefied and rendered lighter, and consequently the air below presses in through the ash pit; and if the bottom of the grate is kept clear, a strong current of air circulates directly through the fire, and supplies it constantly with this necessary ingredient. On similar principles the register stoves are constructed. In these the vent or chimney coming very near the grate, the air below it is forced through the fuel, and by enlarging or contracting the vent, the current of air is increased or diminished. The bath and pantheon stoves are also found to produce more heat in proportion to the quantity of fuel than common open grates, because they are usually set high, and the ash-pit or aperture below being closed on three sides, a considerable part of the air which enters

enters it is forced up through the fire. The ſame reaſons will alſo ſatisfactorily account for the effects of a common bellows, which brings a ſupply of pure air to unite with the inflammable matter contained in the coal.

The inflammable and pure air, which are apparently conſumed by the proceſs of combuſtion, are in reality, by their union, converted into water, as will be evinced by fixing an alembic head, or any good recipient, to the top of Mr. Argand's lamp, in which a quantity of water will preſently be found, but no ſoot.

There are, however, certain ſubſtances, ſuch as gunpowder, &c. which will burn though the air of our atmoſphere ſhould be excluded, as in the receiver of an air-pump, when the air has been exhauſted. To explain this, it muſt be premiſed, that nitre, or ſome of the ingredients of ſuch compoſitions, contains a large quantity of the baſis of pure air; and it muſt be remembered, that air conſiſts of a certain matter or baſis, which is expanded by a union with the matter or element of fire, but which is alſo capable of exiſting in a more condenſed ſtate. Let it alſo be remembered, that though air, which is a compound body, will not penetrate glaſs, yet the element of fire, or heat, will penetrate glaſs or any other ſubſtance with which we are acquainted. One of the ingredients of air, therefore, is contained in the nitre or gunpowder, and the other (the fire or heat) cannot be excluded. When therefore the matter or elementary part of

 the

the air, is set free from the nitre by accension, it immediately meets with the matter of heat or fire, and becomes embodied into the form of air, and thus an actual supply of that material is generated, though the air of the atmosphere is totally excluded *.

According

* Gunpowder is a mixture, which in an hundred parts contains about 75 of nitre, $9\frac{1}{2}$ of sulphur, and $15\frac{1}{2}$ of charcoal. The effects of gunpowder depend on the sudden production of a quantity of air, which takes place from the decomposition of the nitre. Nitre is composed of a fixed alkali and of nitrous acid, which is itself a compound of the bases of azote and oxygen. The ingredient first inflamed is the sulphur, which sets fire to the charcoal. The nitre is equally dispersed among all the particles of combustible matter, and as its quantity is by much the greatest, each particle of sulphur and charcoal is surrounded with nitre. When combustion, therefore, is once excited in the mass, the oxygen afforded by the nitre carries it on with great rapidity. The oxygen, being withdrawn from the azote, causes it to assume an aeriform state, and by being attracted by the charcoal converts the latter into fixable air. The sulphur also attracting some of the oxygen, but not sufficient to reduce it to the state of a fluid, is partly converted into volatile vitriolic acid, the smell of which is very perceptible. The gunpowder, therefore, is in an instant converted into three kinds of air, which occupy the space of the solid matter. What remains after combustion is a liver of sulphur formed by the union of some portion of that substance with the fixed alkali of the nitre.

The effects, however, of this mixture of nitre, sulphur, and coal, are trifling, in comparison with those of another preparation called fulminating powder. This is made by triturating in a hot marble mortar, with a wooden pestle, three ounces of nitre, two ounces of very dry fixed salt of tartar, and one ounce of

According to the different properties of bodies, they are more or less easily disposed to ignition. Iron is ignited with great difficulty; on the contrary,

of flowers of sulphur, till the whole is very accurately mixed. If a drachm of this powder is exposed to a gentle heat, in an iron ladle, it melts, and soon after produces a detonation as loud as the report of a cannon. 'This phenomenon, which is so much the more astonishing, because its effect is produced without inclosing the powder in any instrument, as is done with gunpowder, may be explained, by observing, 1. That it does not succeed, but by gradually heating the mixture, so as to melt it. 2. That if fulminating powder is thrown on ignited charcoal, it only detonates like nitre, but with very little noise. 3. That a mixture of liver of sulphur with nitre, in the proportion of one part of the former, and two of the latter, fulminates with more rapidity, and produces as loud a report as the composition of sulphur, nitre, and alkali: hence it appears, that when fulminating powder is heated, liver of sulphur is formed before the detonation takes place; and this fact is sufficient to explain the whole appearance. When crystallized nitre and liver of sulphur are exposed to the action of heat, inflammable or hepatic gas is disengaged from the latter, while the salt gives out vital air. Now these two, which together are capable of producing a strong inflammation, as we have observed in the history of inflammable gas, are set on fire by a portion of the sulphur. But as the thick fluid they are obliged to pass through presents a considerable obstacle, and as the whole takes fire at the same instant, they strike the air with such rapidity, that it resists in the same manner as the chamber of a musquet resists the expansion of gunpowder. A proof of this is observable in the effect the fulminating powder has on the ladle in which it explodes. The bottom of this vessel is bulged outwards, and the sides bent inwards, in the same manner as if it had been acted on by a force directed perpendicularly downwards, and laterally inwards.'—*Fourcroy's Chem.* v. ii. p. 388.

trary, not only the phoſphorus of Kunkel, but the pyrophori, which are made of three parts of flour, or any vegetable matter convertible into charcoal, and one of alum, will immediately ignite, on being expoſed to the air in the ordinary heat of our atmoſphere. In this caſe the pyrophorus, which conſiſts of a light ſpongy texture, preſents a large ſurface containing a quantity of inflammable matter to the atmoſphere, and the union of the two ſubſtances immediately ſucceeding, the matter of fire is emitted, and ignition takes place.

Every means, indeed, by which pure air may be attracted and condenſed, will produce flame. It was obſerved in the preceding paragraph, that iron was ignited with difficulty; yet if a very ſmall iron wire is conveyed into a cloſe bottle filled with this air, with a ſmall piece of tinder or any combuſtible matter upon it, to which fire has been communicated, the wire will be obſerved to burn, after the other combuſtible matter is conſumed, with a clear and bright flame, and if there is a large quantity of pure air, the whole of the iron will be converted into a calx.

* Gold precipitated from its ſolution in aqua regia by means of volatile alkali, conſtitutes a ſubſtance called fulminating gold, the effects of which are ſtill more tremendous than thoſe of the preceding compoſitions. An extremely ſmall portion of it is ſufficient to produce alarming, and even fatal effects; and what renders it ſtill more dangerous is, that a mere blow, or a ſlight degree of friction, are ſufficient to ignite it. With reſpect to the cauſe of the exploſive power of this ſubſtance, it will be explained when I treat of gold itſelf.

§ It

It has been amply demonſtrated, that the condenſation, not only of pure air, but of every fluid, is attended with the emiſſion of heat or elementary fire; and even the partial condenſation of a fluid, or the reduction of it from a rarer to a denſer ſtate, will produce the ſame effect. Thus air and vapour are rarer fluids than water, and their condenſation into water always produces ſenſible heat; thus fixable air is a denſer fluid than atmoſpherical or pure air; and when a quantity of the latter is by any proceſs converted into the former, a quantity of ſuperfluous caloric is conſequently emitted. This is the caſe in all fermenting bodies, which abſorb a large quantity of the pure air of the atmoſphere, and emit that denſe acid fluid, which always hangs over their ſurface like a vapour, and is univerſally known by the name of fixable air: and this proceſs is always attended with heat, that is, with the detaching of a quantity of elementary fire. The accenſion or ignition of the maſs depends, however, on the ſpeedy emiſſion of the matter of fire, that is, upon the violence of attraction between the two ſubſtances which occaſions the condenſation. When ſulphur, iron-filings, and water, are mixed together and kneaded up into a paſte, the air is rapidly attracted, and the maſs becomes ſpontaneouſly on fire. Hay-ricks and other fermenting maſſes are frequently fired by this kind of ſpontaneous proceſs.

If one of the ſubſtances contains a large quantity of the baſis of pure air, and a ſtrong general attraction exiſts between the ſubſtances a ſimilar effect will

will enſue. Thus, if aqua fortis or ſtrong nitrous acid is poured upon oil of turpentine, the attraction between the inflammable part of the oil and the pure air, which the nitrous acid contains in abundance, will be ſo violent, that the whole will be inſtantaneouſly converted into flame. The ſame effect is produced from a mixture of black wad (an ore of manganeſe, containing much oxygen or pure air) with common linſeed oil. If a quantity of nitrated copper alſo, or the ſalt which is formed by the ſolution of copper in the nitrous acid, is moiſtened, and incloſed in a piece of tin-foil, the ſalt melts or deliqueſces, nitrous fumes are emitted, and the maſs ſuddenly burſts into a flame. This effect is undoubtedly occaſioned by the ſtrong attraction of the tin for the nitrous acid, by which the fire is extricated in ſo rapid a manner as to produce inflammation.

The effects of ſpontaneous inflammation are chiefly ſeen in the mineral world; and to this cauſe is to be attributed a variety of the moſt formidable phenomena of nature, ſuch as volcanoes, earthquakes, &c.

M. Lavoiſier deſcribes an apparatus for aſcertaining the quantities of heat extricated during the combuſtion of different ſubſtances. This contrivance reſts on the propoſition, that when a body is burnt in the center of a hollow ſphere of ice, and ſupplied with air at the temperature of 32°, the quantity of ice melted from the inſide of the ſphere becomes a meaſure of the relative quantities of heat diſengaged.

diſengaged. With this apparatus, phoſphorus, charcoal, and hydrogen gas, gave the following reſults:

One pound of phoſphorus melted one hundred pounds of ice.

One pound of charcoal melted ninety-ſix pounds eight ounces.

One pound of hydrogen gas melted 295 lbs. 9 ounces, 3½ drams.

As a concrete acid is formed by the combuſtion of phoſphorus, it is probable that very little heat or caloric remains in the acid, and, conſequently, that the above experiment gives us very nearly the whole quantity of elementary fire contained in the oxygen gas.

M. Lavoiſier had found, by a former experiment, that one pound of phoſphorus abſorbs one pound eight ounces of oxygen during combuſtion; and ſince, by the ſame operation, one hundred pounds of ice are melted, it follows, that the quantity of caloric contained in one pound of oxygen gas is capable of melting 66 lbs. 10 ounces, 5 drams, 24 grains of ice. By the help of this ſimple contrivance for meaſuring quantities of heat, M. Lavoiſier has been able to arrive at the following concluſions:

'From the combuſtion of phoſphorus, as related in the foregoing experiments, it appears, that one pound of phoſphorus requires 1 lb. 8 oz. of oxygen gas for its combuſtion, and that 2 lbs. 8 oz. of concrete phoſphoric acid are produced.

'The

'The quantity of caloric diſengaged by the combuſtion of one pound of phoſphorus, expreſſed by the number of pounds of ice melted during that operation, is – – – 100.00000.

The quantity diſengaged from each pound of oxygen, during the combuſtion of phoſphorus, expreſſed in the ſame manner, is - 66.66667.

The quantity diſengaged during the formation of one pound of phoſphoric acid, 40.00000. The quantity remaining in each pound of phoſphoric acid, – – – – 0.00000*.

In the combuſtion of one pound of charcoal, 2 lbs. 9 oz. 1 gros 10 grs. of oxygen gas are abſorbed, and 3 lbs. 9 oz. 1 gros 10 grs. of carbonic acid gas are formed.

Caloric, diſengaged during the combuſtion of one pound of charcoal, – – 96.50000†.

Caloric diſengaged during the combuſtion of charcoal, from each pound of oxygen gas abſorbed, – – – – – 37.52823.

Caloric diſengaged during the formation of one pound of carbonic acid gas, – 27.02024.

* We here ſuppoſe the phoſphoric acid not to contain any caloric, which is not ſtrictly true; but, as I have before obſerved, the quantity it really contains is probably very ſmall, and we have not given it a value, for want of a ſufficient data to go upon.

† All theſe relative quantities of caloric are expreſſed by the number of pounds of ice, and decimal parts, melted during the ſeveral operations.

Caloric

Caloric retained by each pound of oxygen after the combuſtion – – – 29.13844.

Caloric neceſſary for ſupporting one pound of carbonic acid in the ſtate of gas – 20.97960.

In the combuſtion of one pound of hydrogen gas, 5 lbs. 10 oz. 5 gros, 24 grs. of oxygen gas are abſorbed, and 6 libs. 10 oz. 5 gros 24 grs. of water are formed.

Caloric from each lb. of hydrogen gas – – – –	295.58950.
Caloric from each lb. of oxygen gas, – – – –	52.16280.
Caloric diſengaged during the formation of each pound of water,	44.33840.
Caloric retained by each lb. of oxygen after combuſtion with hydrogen – – – –	14.50386.
Caloric retained by each lb. of water at the temperature of Zero (32°) – – – –	12.32823.

'When we combine nitrous gas with oxygen gas, ſo as to form nitric or nitrous acid, a degree of heat is produced, which is much leſs conſiderable than what is evolved during the other combinations of oxygen; whence it follows that oxygen, when it becomes fixed in nitric acid, retains a great part of the heat which it poſſeſſed in the ſtate of gas. It is certainly poſſible to determine the quantity of caloric which is diſengaged during the combination

tion of theſe two gaſſes, and conſequently to determine what quantity remains after the combination takes place. The firſt of theſe quantities might be aſcertained, by making the combination of the two gaſſes in an apparatus ſurrounded by ice; but, as the quantity of caloric diſengaged is very inconſiderable, it would be neceſſary to operate upon a large quantity of the two gaſſes in a very troubleſome and complicated apparatus. By this conſideration, Mr. de la Place and I have hitherto been prevented from making the attempt. In the mean time, the place of ſuch an experiment may be ſupplied by calculations, the reſults of which cannot be very far from truth.

'Mr. de la Place and I deflagrated a convenient quantity of nitre and charcoal in an ice apparatus, and found that twelve pounds of ice were melted by the deflagration of one pound of nitre. We ſhall ſee, in the ſequel, that one pound of nitre is compoſed, as under, of

Pot-aſh	7 oz.	6 gros	51.84 grs.	= 4515.84 grs.
Dry acid	8	1	21.16	= 4700.16.

The above quantity of dry acid is compoſed of

Oxygen	6 oz.	3 gros	66.34 grs.	= 3738.34 grs.
Azote	1	5	25.82	= 961.82.

'By this we find that, during the above deflagration, 2 gros $1\frac{1}{3}$ gr. of charcoal have ſuffered combuſtion,

buſtion, along with 3738.34 grs. or 6 oz. 3 gros 66.34 grs. of oxygen. Hence, ſince 12 lbs. of ice were melted during the combuſtion, it follows, that one pound of oxygen burnt in the ſame manner would have melted 29.58320 lbs of ice. To which the quantity of caloric, retained by a pound of oxygen after combining with charcoal to form carbonic acid gas, being added, which was already aſcertained to be capable of melting 29.13844 lbs. of ice, we have for the total quantity of caloric remaining in a pound of oxygen, when combined with nitrous gas in the nitric acid 58.72164; which is the number of pounds of ice the caloric remaining in the oxygen in that ſtate is capable of melting.

'We have before ſeen that, in the ſtate of oxygen gas, it contained at leaſt 66.66667; wherefore it follows that, in combining with azote to form nitric acid, it only loſes 7.94502. Farther experiments upon this ſubject are neceſſary to aſcertain how far the reſults of this calculation may agree with direct fact. This enormous quantity of caloric retained by oxygen in its combination into nitric acid, explains the cauſe of the great diſengagement of caloric during the deflagrations of nitre; or, more ſtrictly ſpeaking, upon all occaſions of the decompoſition of nitric acid.

'Having examined ſeveral caſes of ſimple combuſtion, I mean now to give a few examples of a more complex nature. One pound of wax-taper being

being allowed to burn ſlowly in an ice apparatus, melted 133 lbs. 2 oz. $5\frac{1}{3}$ gros of ice. According to my experiments in the Memoirs of the Academy for 1784, p. 606, one pound of wax-taper conſiſts of 13 oz. 1 gros 23 grs. of charcoal, and 2 oz. 6 gros 49 grs. of hydrogen.

‘ By the foregoing experiments, the above quantity of charcoal ought to melt	79.39390 lbs. of ice;
and the hydrogen ſhould melt – – –	52.37605
In all	131.76995 lbs.

‘ Thus, we ſee the quantity of caloric diſengaged from a burning taper, is pretty exactly conformable to what was obtained by burning ſeparately a quantity of charcoal and hydrogen, equal to what enters into its compoſition. Theſe experiments with the taper were ſeveral times repeated, ſo that I have reaſon to believe them accurate *.’

The following is a table of the different degrees of heat, which certain bodies exhibit in given circumſtances, eſtimated according to Fahrenheit's ſcale, and collected from different authors.

* Lavoiſier's Chemiſtry.

A Scale

A Scale of Heat.

The firſt part of this table is taken from Mr. Wedgwood's ſcale, according to his clay pyrometer.

	Fahr.	Wedg.
Extremity of the ſcale of Mr. Wedgwood's thermometer — —	32277°	240°
Greateſt heat of his ſmall air furnace	21877	160
Caſt-iron melts — —	17977	130
Greateſt heat of a common ſmith's forge — — —	17327	125
Welding heat of iron, greateſt —	13427	95
- - - - - - - - - - -, leaſt —	12777	90
Fine gold melts — —	5237	32
Fine ſilver melts — —	4717	28
Swediſh copper melts — —	4587	27
Braſs melts — — —	3807	21
Heat by which his enamel colours are burnt on — —	1857	6

	Fahr.
Iron with a white ſparkling heat —	2780°
Iron with a heat almoſt white — —	2080
The heat of live coals without blowing, perhaps about — — —	1650
Iron with a glowing red by day-light —	1600
Iron juſt red-hot by day-light — —	1120
Iron juſt red-hot in the dark — —	1000
Greateſt heat of lead in fuſion — —	820
Colours of iron are burned off —	800

	Fahr.
Mercury boils, by ſome placed at 600 —	700
Poliſhed iron takes a full blue — —	700
Poliſhed iron takes a purple — —	660
Linſeed oil boils, by ſome at 600 —	620
Lead melts — — —	610
Poliſhed iron takes a ſtraw colour —	605
Oil of vitriol boils — — —	546
Braſs takes a blue colour — —	500
Biſmuth melts — — —	460
Tin-foil and biſmuth melt — —	450
Tin melts — — —	408
Equal parts of tin and biſmuth melt —	283
Equal parts of tin, lead, and biſmuth melt	220
Water boils — — —	212
Brandy boils — — —	190
Rectified ſpirit of wine boils — —	175
Serum of blood and white of eggs coagulate	156
Bees-wax melts — — —	142
Greateſt heat of water which the hand can well bear — — —	114
Heat of the Sirocco wind at Palermo, in Sicily — — — —	112
Violent ſeveriſh heat — —	108
Heat of the ſkin of ducks, geeſe, and pidgeons — — — —	106
Heat of the ſkin of cats, dogs, ſheep, &c.	103
Heat of the human body in health —	98
Heat of a hive of bees — —	97
Sultry weather — — —	75
Ordinary ſummer heat — —	65

Water

	Fahr.
Water juſt freezing, or ice juſt melting —	32°
Milk freezes — — —	30
Vinegar of ordinary ſtrength froze at —	27
Strong wines froze at — —	20
A mixture of ſnow and ſalt ſinks the thermometer to — — —	0
Greateſt natural cold obſerved in England	3
Weak ſpirit of wine froze — —	33
Mercury freezes about — —	39

As mercury contracts irregularly on freezing, no cold below this can be obſerved by the thermometers now in uſe.

Book III.

Chap. I.

HISTORY OF DISCOVERIES CONCERNING LIGHT, &c.

Opinions of the Platonics.—Of Aristotle.—Of Alhazen.—Of Roger Bacon.—The Invention of Spectacles.—Treatise of Maurolycus on Vision.—Long and short Vision.—Reason that the Sun's Image appears round, though the Rays pass through an angular Aperture.—Invention of the Camera Obscura.—Conjectures of Fletcher on the Rainbow.—Invention of the Telescope.—Supposed to be by Zacharias Jansen.—Galileo.—Kepler.—Invention of the Microscope.—Tycho Brahe.—Reformation of distorted Images.—Snellius and Hortensius.—Descartes.—Scheiner.—Velocity of Light discovered.—Boyle's Discoveries on Colours.—Grimaldi.—Gregory.—Newton; his Discoveries on Colours.—On Refrangibility.—Bolognian Stone.—Baldwin's Phosphorus, &c.—Bradley.—Bouguer.—Melville.—Dolland.—De la Motte.—Delaval.

THE most ancient hypothesis, which leads to the true theory of light and colours, is that of the Platonics, namely, that light, from whatever it proceeds, is propagated in right lines; and that when it is reflected from the surfaces of polished bodies, the angle of incidence is equal to the angle of of reflexion. To this may be added the opinion of Ariſtotle, who ſuppoſed that rainbows, halos, and mock ſuns, were occaſioned by the reflexion of the ſun beams in different circumſtances. We have reaſon to believe, that the uſe of convex glaſſes, both as magnifiers and as burning glaſſes, was not unknown to the ancients, though the theory was not underſtood. The magnifying power of glaſſes, and ſome other optical phenomena, were alſo largely treated of by Alhazen, an Arabic philoſopher of the twelfth century. Theſe obſervations were followed by thoſe of Roger Bacon, who demonſtrates by actual experiment, that a ſmall ſegment of a glaſs globe would greatly aſſiſt the ſight of old perſons; and from the hints afforded by theſe two philoſophers, it is not unreaſonable to conclude, that the invention of ſpectacles proceeded. Concerning the actual author of this uſeful invention, we have no certain information; we only find, that it was generally known about the beginning of the fourteenth century.

In the year 1575, Maurolycus, a teacher of mathematics at Meſſina, publiſhed a treatiſe on optics, in which he demonſtrates, that the cryſtalline humour of the eye is a lens, which collects the rays of light proceeding from external objects, and throws them on the retina, or optic nerve. From this principle he was led to diſcover the reaſon of what is called ſhort and imperfect ſight. In the one caſe, the rays converge too ſoon; in the other, they do not converge ſoon enough. Hence ſhort-ſighted perſons are relieved by a concave glaſs, which cauſes the rays to diverge in ſome degree before they enter the eye, and renders it more difficult for them to converge ſo faſt as they would have done after entering the cryſtalline humour; hence, too, he proves, that a convex lens is of uſe to perſons who have weak, but long ſight, by cauſing the rays to converge ſooner, and in a greater quantity, than would otherwiſe happen. He was the firſt, alſo, that ſolved a problem, which had cauſed much perplexity in the ancient ſchools, reſpecting the ſun's image appearing round, though the rays that form it are tranſmitted into a dark room through an angular aperture. He conſidered, that as the rays of light are conſtantly proceeding, in every direction, from every part of the ſun's diſk, "they muſt be croſſing each other from the extreme part of it in every point of the aperture; ſo that every ſuch point will be the apex of two cones, of which the baſe of the one is the ſun's diſc, and that of the other his image on the oppoſite wall." The whole image, therefore, conſiſts of a number of images, all of which are circular; the image of the ſun formed of thoſe images muſt be circular alſo; and it will approach the nearer a perfect circle, the ſmaller the aperture, and the more diſtant the image.

Nearly about the ſame time, Johannes Baptiſta Porta, of Naples, invented the camera obſcura; and his experiments upon that inſtrument convinced him that light is a body, by the intromiſſion of which into the eye viſion is performed; for it ought

to

to be remarked, that before his time the opinion was pretty general, that viſion depended upon what was termed *viſual* rays, proceeding from the eye. In this the ſyſtem of Porta correſponds nearly with that of Maurolycus; but it ought to be remarked, that the diſcoveries of each of theſe two philoſophers were unknown to the other. He ſhews, moreover, that a defect of light is remedied by the dilatation of the pupil, which contracts involuntarily when expoſed to a ſtrong light, and opens when the light is faint and languid.

One Fletcher, of Breſlau, in 1571, endeavoured to account for the phenomena of the rainbow, by a double reflexion and one refraction; but Antonio de Dominis, whoſe treatiſe was publiſhed in 1611, was the firſt who came near to the true theory. He deſcribes the progreſs of the ray of light through each drop of the falling rain; he ſhews that it enters the upper part of the drop, where it ſuffers one refraction; that it is reflected once, and then refracted again, ſo as to come directly to the eye of the ſpectator; why this refraction ſhould produce the different colours was reſerved for Sir I. Newton to explain.

The latter end of the ſixteenth century was illuſtrious for the invention of teleſcopes. It is generally allowed to have been caſual. That effect of refraction, which cauſes the rays of light, in paſſing through a denſe medium thicker in the middle, to converge to a point, and alſo that which takes place when they paſs through one thicker at the extremities, had been long obſerved; and the aſſiſtance which convex and concave glaſſes afforded to the ſight had brought them into common uſe. The inventor of the teleſcope is not certainly known. The moſt probable account is, that one Zacharias Janſen, a ſpectacle maker of Middleburgh, trying the effect of a concave and convex glaſs united, found that, placed at a certain diſtance from each other, they had the property of bringing diſtant objects apparently nearer to the eye. Teleſcopes were greatly improved by Galileo, who made one to magnify thirty-three times, and with this he made all his wonderful aſtronomical diſcoveries.

The rationale of teleſcopes was, however, not explained till Kepler, who deſcribed the nature and the degree of refraction, when light paſſed through denſer or rarer mediums, the ſurfaces of which are convex or concave, namely, that it correſponds to the diameter of the circle of which the convexity or concavity are portions of arches. He ſuggeſted ſome improvements in the conſtruction of teleſcopes, which, however, were left to others to put in practice.

To the Janſens we are alſo indebted for the diſcovery of the microſcope; an inſtrument depending upon exactly the ſame principles as the former. In fact, it is not improbable that the double lens was firſt applied to the obſervation of near but minute objects, and afterwards, on the ſame principles, to objects

objects which appeared minute on account of their diſtance.

Much attention was given by Kepler to the inveſtigation of the law of refraction; but he was able to advance no nearer the truth than the obſervation, that when the incident ray does not make an angle of more than thirty degrees with the perpendicular, the refracted ray proceeds in an angle which is about two-thirds of it. Many diſputes aroſe about the time of Kepler (1600) upon this ſubject, but it appears that little was effected by them in the cauſe of truth.

Kepler was more ſucceſsful in purſuing the diſcoveries of Maurolycus and B. Porta. He demonſtrated that images of external objects were formed upon the optic nerve by the foci of rays coming from every part of the object; he alſo obſerved, that theſe images are inverted; but this circumſtance, he ſays, is rectified by the mind, which, when an impreſſion is made on the lower part of the retina, conſiders it as made by rays proceeding from the higher parts of the object. Habit is ſuppoſed to reconcile us to this deception, and to teach us to direct our hands to thoſe parts of objects from which the rays proceed. Tycho Brahe, obſerving the apparent diminution of the moon's diſk in ſolar eclipſes, imagined that there was a real diminution of the diſk by the force of the ſun's rays; but Kepler ſaid, that the diſk of the moon does not appear leſs in conſequence of being unenlightened, but rather that it appears at other

times

times larger than it really is, in consequence of its being enlightened. For pencils of rays from such distant objects generally come to their foci before they reach the retina, and consequently diverge and spread when they reach it. For this reason, he adds, different persons may imagine the disk to be of different magnitudes, according to the relative goodness of their sight.

In the sixteenth century also many improvements were made in perspective; the ingenious device, in particular, of the reformation of distorted images by concave or convex speculums was invented, but it is uncertain by whom.

The true law of refraction was discovered by Snellius, the mathematical professor at Leyden; but not living to complete it, the discovery was published and explained by Professor Hortensius. Some discoveries of lesser importance were made at this time, among others by Descartes, who very clearly explained the nature and cause of the figure of the rainbow, though he was able to give no account of the colours; he however considered the small portion of water, at which the ray issues, as having the effect of a prism, which was known to have the property of rendering the light, which was transmitted through it, coloured.

In 1625, the curious discovery of Scheiner was exhibited at Rome, which ascertains the fact, that vision depends upon the images of external objects upon the retina. For taking the eye of an animal, and cutting away the coats of the back part, and presenting

presenting different objects before it, he displayed their images distinctly painted on the naked retina or optic nerve. The same philosopher demonstrated by experiment, that the pupil of the eye is enlarged in order to view remote objects, and contracted when we view those which are near. He shewed, that the rays proceeding from any object, and passing through a small hole in a pasteboard, cross one another before they enter the eye; for if the edge of a knife is held on the side next the eye, and is moved along till it in part covers the hole, it will first conceal from the eye that part of the object which is situated on the opposite side of the hole.

Towards the middle of the seventeenth century the velocity of light was discovered by some members of the Royal Academy of Sciences at Paris, particularly Cassini and Roemer, by observing the eclipses of Jupiter's satellites. About the same time Mr. Boyle made his experiments on colours. He proved that snow did not affect the eye by a native but reflected light, a circumstance which, however, at this day, we should scarcely believe was ever necessary to be proved by experiment. By admitting also a ray of light into a dark room, and letting it fall on a sheet of paper, he demonstrated, that white reflected much more light than any other colour; and to prove that white bodies reflect the rays outwards, he adds, that common burning-glasses will not, for a long while, burn or discolour white paper; on the contrary, a concave mirror of black marble did not reflect the rays of the sun with near so much power

power as a common concave mirror. The ſame effect was verified by a tile, one half of the ſurface of which was white, and the other black.

Some experiments were made about this time on the difference of the refractive powers of bodies; and the firſt advance to the great diſcoveries by means of the priſm was made by Grimaldi, who obſerved, that a beam of the ſun's light, tranſmitted through a priſm, inſtead of appearing round on the oppoſite wall, exhibited an oblong image of the ſun. Towards the cloſe of this century the reflecting teleſcope was invented by our countryman James Gregory.

The reader will ſoon perceive how very imperfect all the preceding diſcoveries were in compariſon with thoſe of Sir I. Newton. Before his time, little or nothing was known concerning colours; even the remark of Grimaldi reſpecting the oblong figure of the ſun, made by tranſmitting the rays through a priſm, was unknown to our great philoſopher, having been publiſhed only the year before. This, however, it appears, was the firſt circumſtance which directed the attention of Newton to the inveſtigation of the theory of colours. Upon meaſuring the coloured image, which was made by the light admitted into a dark chamber through a priſm, he found that its length was five times greater than its breadth. So unaccountable a circumſtance induced him to try the effect of two priſms; and he found that the light, which by the firſt priſm was diffuſed into an oblong, was by the ſecond

second reduced to a circular form, as regularly as if it had passed through neither of them. After many conjectures and experiments relating to the cause of these phenomena, he at length applied to them what he calls the experimentum crucis. He took two boards, and placed one of them close to the window, so that the light might be admitted through a small hole made in it, and after passing through a prism might fall on the other board, which was placed at about twelve feet distance, and in which there was also a small aperture, in order that some of the incident light might pass through it. Behind this hole, in the second board, he also placed a prism, so that the light, after passing both the boards, might suffer a second refraction before it reached the wall. He then moved the first prism in such a manner as to make the several parts of the image cast upon the second board pass successively through the hole in it, that he might observe to what places on the wall the second prism would refract them. The consequence was, that the coloured light, which formed one end of the image, suffered a refraction considerably greater than that at the other end; in other words, rays of light of one colour were more refrangible than those of another. The true cause, therefore, of the length of the image was evident, since it was proved by the experiment, that light was not homogenial, but consisted of different particles or rays, which were capable of different degrees of refrangibility, and according to which they are transmitted through the prism prifm to the oppofite wall. It was further evident from thefe experiments, that as the rays of light differ in refrangibility, fo they alfo differ in exhibiting particular colours, fome rays producing the colour red, others that of yellow, blue, &c. and of thefe different-coloured rays, feparated by means of the prifm according to their different degrees of refrangibility, the oblong figure on the wall was compofed. But to relate the great variety of experiments, by which he demonftrated thefe principles, or the extenfive application of them, would lead me too much into detail; let it fuffice to fay, that he applied his principles to the fatisfactory explanation of the colours of natural bodies, of the rainbow, and of moft of the phenomena of nature, where light and colour are concerned; and that almoft every thing which we at prefent know upon thefe fubjects was laid open by his experiments.

His obfervations on the different refractive powers of different fubftances are curious and profound; but chemiftry was at that period fcarcely in a ftate fufficiently advanced to warrant all his conclufions. The general refult is, that all bodies feem to have their refractive powers proportional to their denfities, excepting fo far as they partake more or lefs of fulphureous or oily particles.

The difcovery of the different refrangibility of the component rays of light fuggefted defects in the conftruction of telefcopes, which were before unthought of, and in the creative hand of a Newton led to fome no lefs extraordinary improvements in them.

them. It is evident, that ſince the rays of light are of different refrangibilities, the more refrangible will converge to a focus much ſooner than the leſs refrangible, conſequently that the whole beam cannot be brought to a focus in any one point, ſo that the focus of every object-glaſs will be a circular ſpace of conſiderable diameter, namely, about one fifty-fifth of the aperture of the teleſcope. To remedy this, he adopted Gregory's idea of a reflector, with ſuch improvements as have been the baſis of all the preſent inſtruments of this kind.

When a ſcience has been carried to a certain degree of perfection, ſubſequent diſcoveries are too apt to be conſidered as of little importance. The real philoſopher will not, however, regard the diſcoveries on light and colours, ſince the time of Newton, as unworthy his attention. By a mere accident, a very extraordinary property in ſome bodies of imbibing light, and afterwards emitting it in the dark, was obſerved. A ſhoemaker of Bolognia, being in queſt of ſome chemical ſecret, calcined, among other things, ſome ſtones of a particular kind, which he found at the bottom of Mount Peterus, and caſually obſerved, that when theſe ſtones were carried into a dark place after having been expoſed to the light, they poſſeſſed a ſelf-illuminating power. Accident afterwards diſcovered the ſame property in other ſubſtances. Baldwin of Miſnia, diſſolving chalk in aqua-fortis, found that the reſiduum, after diſtillation, exactly reſembled the Bolognian ſtone in retaining and

emitting

emitting light, whence it now has the name of Baldwin's phosphorus; and M. Du Fay observed the same property in all substances that could be reduced to a calx by burning only, or after solution in nitrous acid. These facts seem to establish the materiality of light.

Some very accurate calculations were made about the year 1725 by Dr. Bradley, which afforded a more convincing proof of the velocity of light, and the motion of the earth in its orbit. Nor must we forget M. Bouguer's very curious and accurate experiments for ascertaining the quantity of light which was lost by reflexion, the most decisive of which was by admitting into a darkened chamber two rays of light, one of which he contrived should be reflected, and the other fall direct on the opposite wall; then by comparing the size of the apertures, by which the light was admitted (that through which the direct ray proceeded being much smaller than that through which the reflected ray was suffered to pass, and the illumination on the wall being equal in both) he was enabled to form an exact estimate of the quantity of light which was lost. To prove the same effect with candles, he placed himself in a room perfectly dark, with a book in his hand, and having a candle lighted in the next room, he had it brought nearer to him till he could just see the letters, which were then twenty-four feet from the candle. He then received the light of the candle reflected by a looking-glass upon the book, and he found the whole distance of the book from the

source

ſource of the light (including the diſtance from the book to the looking-glaſs) to be only fifteen feet; whence he concluded, that the quantity of direct light is to that of reflected as 576 to 225; and ſimilar methods were purſued by him for meaſuring the proportions of light in general *.

The ſpeculations of Mr. Melville, concerning the blue ſhadows which appear from opake bodies in the morning and evening, when the atmoſphere is ſerene, are far from unintereſting. Theſe phenomena he attributes to the power which the atmoſphere poſſeſſes of reflecting the fainter and more refrangible rays of light, the blue, violet, &c. and upon this principle he alſo explained the blue colour of the ſky, and ſome other phenomena.

The ſame period produced Mr. Dollond's great improvement in the conſtruction of teleſcopes. It conſiſts in uſing three glaſſes of different refractive powers, crown and flint glaſs, which correct each other. The great diſperſion of the rays which the flint-glaſs produces, is the effect of the lead, and is in proportion to the quantity of that metal, which is uſed in its compoſition. Mr. Martin found the refractive powers of different glaſſes to be in proportion to their ſpecific gravity.

Several diſcoveries and improvements have been made ſince the time of Newton in that branch of optics which relates more immediately to viſion;

* See an accurate deſcription of M. Bouguer's inſtruments, Prieſtley's *Hiſt. of Optics,* Per. vi. ſ. 7.

but theſe, being rather foreign to the chief ſubject of this chapter, I ſhall not detail. One diſcovery only I ſhall mention, becauſe it not only is curious in itſelf, but becauſe it led to the explanation of ſeveral circumſtances relating to viſion. M. De la Motte, a phyſician of Dantzick, was endeavouring to verify an experiment of Scheiner, in which a diſtant object appeared multiplied when viewed through ſeveral holes made with the point of a pin in a card, not further diſtant from one another than the diameter of the pupil of the eye; but notwithſtanding all his labour, he was unable to ſucceed, till a friend happening to call upon him, he deſired him to make the trial, and it anſwered perfectly. This friend was ſhort-ſighted; and when he applied a concave glaſs cloſe to the card, the object, which ſeemed multiplied before, now appeared but one.

The laſt, though not leaſt ſucceſsful adventurer in this branch of ſcience, is Mr. Delaval, who, in a paper read before the Philoſophical Society of Mancheſter in 1784, has endeavoured, with great ingenuity, to explain the permanent colours of opake bodies. The majority of thoſe philoſophers, who have treated of light and colours, have, he obſerves, ſuppoſed that certain bodies or ſurfaces reflected only one kind of rays, and therefore exhibited the phenomena of colours; on the contrary, Mr. Delaval, by a variety of well conducted experiments, evinced, that colours are exhibited, not by reflected, but by tranſmitted light. This he proved by covering coloured glaſſes and other tranſparent

tranſparent coloured media, on the further ſurface, with ſome ſubſtance perfectly opake, when he found they reflected no colour, but appeared perfectly black. He concludes, therefore, as the fibres or baſes of all vegetable, mineral, and animal ſubſtances are found, when cleared of heterogeneous matters, to be perfectly *white*, that the rays of light are in fact reflected from theſe white particles, through coloured media, with which they are covered; that theſe media ſerve to intercept and impede certain rays in their paſſage through them, while, a free paſſage being left to others, they exhibit, according to theſe circumſtances, different colours. This he illuſtrates by the fact remarked by Dr. Halley, who, in diving deep into the ſea, found that the upper part of his hand, when extended into the water from the diving bell, reflected a deep red colour, while the under part appeared perfectly green. The concluſion is, that the more refrangible rays were intercepted and reflected by particles contained in the ſea-water, and were conſequently reflected back by the under part of the hand; while the red rays, which were permitted to paſs through the water, were in the ſame manner reflected by the upper part of the hand, which therefore appeared of a red roſe colour. Thoſe media, our author thinks, tranſmit coloured light with the greateſt ſtrength which have the ſtrongeſt refractive power.

Chap. II.

OF THE NATURE OF LIGHT.

Various Opinions on the Action of Light.—Theory of a vibrating Medium; supported by Descartes, &c.—Objections to this Theory.—Light consists of infinitely minute Particles projected from the luminous Body.—Inquiry respecting the Identity of Light and Fire.—Experiments of Mr. Boyle.—Why Light is not always accompanied with Heat.—Velocity of Light.—Light always moves in Right Lines.—Rarity of Light.—Force or Momentum of Light.—Mitchell's Experiment.—Inquiry how far the Sun's Magnitude is diminished by the Emission of Light.—Light subject to the ordinary Laws of Nature.—Light attracted by the Bolognian Phosphori.—The same Property in Diamonds, and other Precious Stones.—Refraction of Light.—Reflexion.—Theory of Colours.

NUMEROUS opinions have successively been adopted concerning this wonderful fluid. It has been sometimes considered as a distinct substance, sometimes as a quality, sometimes as a cause, frequently as an effect; by some regarded as a compound, and by others as a simple substance. Des Cartes and other philosophers of high repute have imagined that the sensation which we receive from light is to be attributed entirely to the vibrations of a subtile medium, or fluid, which is diffused throughout the universe, and which is put into action by the impulse of the sun. In this view they consider confider light as analogous to found, which is known to depend entirely on the pulfations of the air upon the auditory nerves; and in fupport of this opinion, it has been even lately urged *, 1ft. That fome diamonds, on being rubbed or chafed, are luminous in the dark. 2d. That an electric fpark, not larger, but much brighter, than the flame of a candle, may be produced, and yet that no part of the electric fluid is known to efcape, in fuch a cafe, to diftant places, but the whole proceeds in the direction to which it is deftined by the hand of the operator. Weaker or ftronger fparks of this fluid are alfo known to differ in colour; the ftrongeft are white and the weakeft red, &c.

To this opinion, however, there are many preffing and, indeed, infurmountable objections. 1ft, The velocity of found bears a very fmall proportion to that of light. Light travels, in the fpace of eight minutes, a diftance in which found could not be communicated in feventeen years; and even our fenfes may convince us, if we attend to the explofion of gunpowder, &c. of the almoft infinite velocity of the one compared with that of the other. 2dly, If light depended altogether on the vibrations of a fluid, no folid reafon can be affigned why this fluid fhould ceafe to vibrate in the night, fince the fun muft always affect fome part of the circumambient fluid, and produce a perpetual day. 3dly, The

* See Dr. Franklin's works; and Profeffor Boudoin's Memoir. *Tranfactions of American Academy*, Vol. i.

artifice of candles, lamps, &c. would be wholly unneceſſary upon this hypotheſis, ſince, by a quick motion of the hand, or of a machine contrived for this purpoſe, light might on all occaſions be eaſily produced. 4thly, Would not a ray of light, admitted through a ſmall aperture, put in motion, according to this theory, the whole fluid contained in a chamber. In fact, we know that light is propagated only in right lines, whereas ſound, which depends upon vibration, is propagated in every direction. 5thly, The ſeparation or extenſion of the rays, by means of the priſm, can never be accounted for by the theory of a vibrating medium. 6thly, The texture of many bodies is actually changed by expoſure to the light. The juice of a certain ſhell-fiſh contracts, it is well known, a very fine purple colour, when permitted to imbibe the rays of the ſun; and the ſtronger the light is the more perfect the colour. Pieces of cloth wetted with this fluid become purple, even though incloſed in glaſs, if the ſolar light only is admitted; but the effect is totally excluded by the intervention of the thinneſt plates of metal, which exclude the light. Some of the preparations of ſilver alſo, ſuch as luna cornea, will remain perfectly white, if covered from the light, but contract a dark purple colour when expoſed to it; and even the colour of plants is derived from the light, ſince a plant which vegetates in darkneſs will be perfectly white. As colour is imparted by light, ſo it is alſo deſtroyed by it. It muſt have fallen within the obſervation of every reader, that ſilks, and other ſtuffs

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of delicate colours, are greatly affected by the action of light. Experiments have been made upon the same stuffs by exposing them to both heat and moisture in the dark, and also by exposing them to the light in the vacuum of an air pump, and it was found by all these experiments, that the change of colour was to be ascribed to the action of light *. 7thly, With respect to the emission of light by diamonds and other stones, it is easily accounted for upon other principles; and the arguments founded upon the electric spark not being sensibly diminished will meet with a satisfactory solution by considering the extreme rarity of light, and the minuteness of its particles.

It is, therefore, almost universally agreed by the moderns, that light consists of a number of extremely minute particles, which are actually projected from the luminous body, and act by their projectile force upon our optic nerve. Concerning the nature of these particles, or rather of the matter of which they consist, there is less unanimity in the philosophical world.

It is an opinion supported by the most respectable names, that light is a substance perfectly distinct from the matter of fire, and which excites ignition

* "It was conjectured by some, that the rays of the sun dispersed those parts of the bodies on which colours depended; but Bonzius observed, that when ribbons were exposed on white paper, the colours vanished from both their sides, but that nothing could be found near the places where they had lain." *Priestley's Optics*, 381.

when concentrated by a burning glafs, merely by its mechanical force upon the matter of heat. Others of equal eminence have contended, that light is no other than fire in a projectile ftate. Fire, according to thefe philofophers, is produced by the accumulation or concentration of the particles; light is the effect of the rapid projectile motion of the fame particles. Fire or heat may therefore exift to a confiderable degree, as it is found to do occafionally in metallic bars, without being fufficiently difengaged to affume the projectile ftate, and to be forcibly emitted or projected from the burning body. The fame matter may alfo exift in its active and projectile ftate, or, in other words, in the form of light, but too much diffufed to produce the fenfation of burning, or to effect the diffolution of any body, or the feparation of its parts by combuftion. To the great elafticity of the matter of fire, fo obvious in all the phenomena of fluidity, both thefe effects are afcribed. When a quantity of this matter is introduced into any folid body, the repulfion which exifts between its particles will occafion the diffolution of that body; and when it becomes perfectly free and difengaged, the fame repulfion will caufe a quantity of its particles to be emitted with a rapid projectile force, and will produce the effects of light *. The light of the fun is confidered as " the fame matter propelled by the fame powers, in greater

* ' When we confider that the elafticity of aeriform fluids, is owing to the matter of fire; that a cannon ball is propelled only

greater quantity and with greater vigour *." The atmoſphere through which light has to paſs in proceeding from the ſun to us is in all probability of infinitely greater purity than ours, and conſequently, according to the laws of motion, the projectile force of the rays of light is very little diminiſhed in their paſſage from the great ſource of both light and fire.

The theory which is here advanced appears to reſt chiefly on the great fact of the ſun's rays, when concentrated by a burning glaſs, producing all the phenomena and effects of elementary fire. There are, however, other facts which countenance the opinion. Sir Iſaac Newton obſerves, that all bodies, when heated beyond a certain degree, emit light, and ſhine. Light alſo accompanies the electric fire, whenever it exiſts in a diſengaged or projectile ſtate.

only by the exceſs of the repellant powers of parts of this matter, above the forces with which they are attracted by the groſs parts of gunpowder, or of the airs emitted during the deflagration of it; that the velocity of the ball is incomparably leſs than it would be if it were ſhot through an unreſiſting medium; and that even this latter velocity would be an inadequate repreſentation of that, with which the parts of the fiery matter are ſhot forth, in the firſt inſtant of their liberation from the combuſtible body which held them cloſely approximated; we find the natural powers already deſcribed, ſufficient in themſelves, for the projection of theſe parts, with all the velocity experienced in the light of flaming bodies on earth, and to every diſtance at which it has been perceived.'

Higgins's Experiments and Obſervations, p. 338.

* Higgins's Experiments and Obſervations, p. 339.

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The abſorption of light by the darker colours is alſo found to have an extraordinary effect in the production of heat; but the experiments to this effect have been already related *.

That light (or more properly according to this theory, the matter of fire) does not always produce actual heat, is accounted for from the minuteneſs of the particles, and the extreme rarity which, from its repulſive principle, the fluid is enabled to aſſume. It was before ſtated that light muſt be exceedingly concentrated to produce ignition. A plane mirror reflects the light in too diffuſed a ſtate; but a concave mirror collects and converges the particles to a point, and is therefore capable of producing ignition; and yet we have ſeen that the light of the moon will not, in the moſt condenſed ſtate, produce the leaſt degree of heat, though the moſt delicate thermometers ſhould be employed. The light which is emitted by putreſcent ſubſtances, by the glow-worm, and ſome other inſects, is analogous to the light of the moon in this reſpect; it is of too faint and rare a nature to produce heat or ignition. In the ſame manner, when the rays of light paſs through a tranſparent medium, they ſucceed each other at an immenſe diſtance †. If, therefore, the rays concentrated by the moſt powerful burning glaſs are made to paſs through a phial containing ſpirits of wine, or through any other tranſparent inflammable ſubſtance, the latter will not be ſet on fire; but if

* See p. 76.

† That of 1,000 miles.

there

there is any opake body (as a ſpoon or other veſſel) placed under the ſpirit or the tranſparent body, which by abſorbing may ſerve to accumulate the particles of light, the ſpirit or inflammable matter will be immediately inflamed. Conformably to theſe principles it is found, that the atmoſphere is not warmed by the mere paſſage of the ſun's rays through it, but chiefly by the heat which is collected by the earth, and which is thence imparted to the air. Thus the air, at the ſummits of high mountains, is always cold, becauſe they are too much elevated above the general ſurface of the earth to derive any conſiderable advantage from this circumſtance.

When theſe facts are fairly conſidered, the ſyſtem which ſuppoſes light to be a modification of the matter of fire, or a combination of that element with ſome unknown principle, muſt be allowed to be at leaſt probable. It has however been cuſtomary to conſider diſtinctly the properties of light, without a reference to its analogy with the matter of fire, and in this mode it will be neceſſary, on the preſent occaſion, to proceed.

The firſt remarkable property of light is its amazing VELOCITY. In the ſhort ſpace of *one ſecond* a particle of light traverſes an extent of *one hundred and ſeventy thouſand miles* *, which is ſo much ſwifter than the progreſs of a cannon ball, that the light is enabled to paſs a ſpace in about eight minutes, which could not be paſſed with the

* Nicholſon's Phil. vol. i, p. 258.

ordinary

ordinary velocity of a cannon ball in leſs than thirty-two years *. The velocity of light is alſo found to be uniform, whether it is original, as from the ſtars, or reflected only, as from the planets.

The mode of calculating the velocity of light is a branch of aſtronomy rather than of natural hiſtory. It will ſuffice therefore in this place to remark, that by mathematical obſervations made upon the tranſits of Venus in 1761 and 1769, the diameter of the earth's orbit was found to be about 163,636,800 geographical miles. When, therefore, the earth happens to be on that ſide of her orbit which is oppoſite to Jupiter, an eclipſe of his ſatellites, or any other appearance in that planet, is obſerved to take place fifteen or ſixteen ſeconds later than it would have done if the earth had been on that ſide of her orbit which is neareſt to Jupiter †. From the very accurate obſervations of Dr. Bradley, it appears that the light of the ſun paſſes from that luminary to the earth in eight minutes and twelve ſeconds.

The next property of light, to which it is proper to advert, is, that it is detached from every luminous or viſible body in all directions, and conſtantly moves in RIGHT LINES. It is evident that the particles of light move continually in right lines, ſince they will not paſs through a bended

* Nicholſon's Phil. vol. i. p. 257.

† See Newton's Optics, l. ii. p. 3. prop. 11. Prieſtley's Optics, p. 140. Nicholſon's Phil. vol. i. p. 136.

tube,

tube, and ſince if a beam of light is in part intercepted by any intervening body, the ſhadow of that body will be bounded by right lines paſſing from the luminous body, and meeting the lines which terminate the interceding body. This being granted, it is obvious, that the rays of light muſt be emitted from luminous bodies in every direction, ſince, whatever may be the diſtance at which a ſpectator is placed from any viſible object, every point of the ſurface which is turned towards him is viſible to him, which could not be upon any other principle.

The RARITY of light, and the minuteneſs of its particles, are not leſs remarkable than its velocity. If indeed the Creator had not formed its particles infinitely ſmall, their exceſſive velocity would be deſtructive in the higheſt degree. It was demonſtrated, that light moves about two million of times as faſt as a cannon ball *. The force with which moving bodies ſtrike, is in proportion to their maſſes multiplied by their velocities; and conſequently if the particles of light were equal in bulk to the two millioneth part of a grain of ſand, we ſhould be no more able to endure their impulſe than that of ſand ſhot point blank from the mouth

* A cannon ball flies with a velocity of about a mile in eight ſeconds. Nicholſon's Phil. vol. i. p. 257. During the late ſiege of Gibraltar, there were two boys, who uſed to be ſtationed on the works, and whoſe quick ſight enabled them to give notice to the workmen of the approach of a ball from the enemy's works.—*Drinkwater's Gib.*

of

of a cannon *. The minuteneſs of the rays of light is alſo demonſtrable from the facility with which they penetrate glaſs, cryſtal, and other ſolid bodies, which have their pores in a rectilinear direction, and that without the ſmalleſt diminution of their velocity, as well as from the circumſtance of their not being able to remove the ſmalleſt particle of microſcopic duſt or matter which they encounter in their progreſs. A further proof might be added, that if a candle is lighted, and there is no obſtacle to obſtruct its rays, it will fill the whole ſpace within two miles around it almoſt inſtantaneouſly, and before it has loſt the leaſt ſenſible part of its ſubſtance †.

To the velocity with which the particles of light are known to move may, in a great meaſure, be attributed the extreme rarity and tenuity of that fluid. It is a well-known fact, that the effect of light upon the eye is not inſtantaneous, but continues for a conſiderable time ‡. Now we can ſcarcely conceive a more minute diviſion of time than the one hundred and fiftieth part of a ſecond. If, therefore, one lucid point of the ſun's ſurface emits one hundred and fifty particles of light in one ſecond, we may conclude that this will be ſufficient to afford light to the eye without any ſeeming intermiſſion; and yet, ſuch is the velocity with which light proceeds, that ſtill theſe particles will be at

* Nicholſon's Phil. vol. i. p. 257.

† Enfield's Phil. 131.

‡ Nicholſon's Phil. vol. i. p. 258.

leaſt *one thouſand miles* diſtant from each other *. If it was not indeed for this extreme tenuity of the fluid, it would be impoſſible that the particles ſhould paſs, as we know they do, in all directions without interfering with each other. In all probability the ſplendour of all viſible objects may be in proportion to the greater or leſs number of particles, which are emitted or reflected from their ſurface in a given ſpace of time; and if we even ſuppoſe three hundred particles emitted ſucceſſively from the ſun's ſurface in a ſingle ſecond, ſtill theſe particles will follow each other at the immenſe diſtance of above five hundred miles.

That light is, however, not deſtitute of FORCE or MOMENTUM, has been proved by the experiment of Mr. Mitchel, already mentioned †. On that experiment the following calculation is grounded. If the inſtrument weighed ten grains, and the velocity with which it moved was one inch in a ſecond, the quantity of matter contained in the rays which fell upon the inſtrument in that time was equal to the twelve hundred millioneth part of a grain; the velocity of light exceeding the velocity with which the inſtrument moved in that proportion. The light in this experiment was collected from a ſurface of about three ſquare feet, which reflecting only half what falls upon it, the quantity of matter contained in the rays of the ſun incident upon a ſquare foot and half of ſurface is no more than one twelve hundred mil-

* Prieſtley's Optics, p. 385. † See p. 73.

lioneth part of a grain. But the denſity of the rays of light at the ſurface of the ſun is greater than at the earth in the proportion of 45,000 to 1. There ought therefore to iſſue from one ſquare foot of the ſun's ſurface in one ſecond $\frac{1}{40000}$th part of a grain of matter to ſupply the conſumption of light; that is at the rate of a little more than two grains a day, or about 4,752,000 grains, or 670 pounds in 6,000 years, which would have ſhortened the ſun's diameter about ten feet, if it was formed of matter of the denſity of water only *.

Thus we ſee there are little grounds for any reaſonable apprehenſions concerning the body of the ſun becoming exhauſted by the conſumption or waſte of the matter of light, if the immenſity of his diameter (878,808 Engliſh miles) is conſidered. It is, however, not impoſſible that there are means by which the ſun may be enabled to receive back again a part of that light or fire which he is continually emitting; it is not impoſſible that this world, and the other planets, may have a power of reflecting back a certain portion of their light within the ſphere of the ſun's attraction, or that the fixed ſtars or ſuns may have ſome power of repleniſhing one another. After all, we have no right to ſuppoſe our world, or the ſyſtem of which it makes a part, deſigned for an eternal duration; its exiſtence is doubtleſs proportioned to the ends which were intended to be accompliſhed in it; but with reſpect to

* Prieſtley's Optics, p. 389.

the

the period of its termination, there is no chain of moral or physical reasoning which appears to conduct to any satisfactory conclusion.

Notwithstanding the minuteness of the particles of light, and the amazing velocity with which they are projected, they are found, by a variety of experiments, to be subject to the same laws of ATTRACTION and repulsion that govern all other bodies. On this principle the majority of philosophers have explained the phenomena of the Bolognian stone, and what are called the solar phosphori.

The discovery of the Bolognian phosphorus, as related by Mr. Lemery, has already been detailed. The property of imbibing and emitting light is not, however, confined to one species, but is common to all the varieties of that mineral, which is called ponderous spar.

The light which they emit bears an analogy to that which they have imbibed. In general, the illuminated phosphorus is red; but when a weak light has been admitted to it, or when it has been received through pieces of white paper, the emitted light is of a pale white *.

It has been already remarked †, that an artificial phosphorus may be obtained from all substances which can be reduced to a calx by burning only, or by solution in the nitrous acid. Some diamonds, however, as well as emeralds and other precious stones, are found to have the same property without

* Priestley's Optics, p. 363, 364. † See Chap. 1.

any chemical preparation; and a diamond has been known to retain its virtue of emitting light, after being buried in wax six hours *. In fact, Beccaria has observed, that almost all natural bodies have the power of imbibing light, and of emitting it in the dark. To metals and water, however, he could not communicate the slightest degree of this property; but he found that although water in its fluid state could not be made to shine in the dark, ice and snow had this property in a remarkable degree †.

The light which is emitted from putrid substances and rotten wood, also that of ignes fatui, and other similar meteors, proceeds from a different cause, and will be explained in another part of this work, to which the subject more properly appertains.

To the principle of attraction Newton has also referred one of the most extraordinary phenomena of light; that on which the science of optics, strictly speaking, principally depends, and on which most of the optical instruments in use are constructed; I speak of what is called the Refraction of light, or that deviation or bending which its rays suffer in passing obliquely out of one medium into another, such as out of air into water, glass, &c.; but this refraction can be observed in passing through transparent mediums only. These mediums, whether

* Priestley's Optics, p. 367.

† Priestley's Optics, p. 368, 369, 370. The nature of these phosphori will be explained more at large under their proper head, in Book VI. Chap. 35.

solid

ſolid or fluid, muſt be conſidered as maſſes whoſe pores, placed in right lines in all directions, are either full of the matter of light, according to the opinions of Deſcartes and Huyghens, or they are ſo conſtructed as to permit the light to paſs in right lines, according to Newton.

There are two circumſtances to be conſidered in the paſſage of the rays of light out of one medium into another: Firſt, the nature of the medium; ſecondly, the obliquity of the rays to the plane which ſeparates the two mediums.

1. The denſer the refracting medium, or that into which the ray paſſes, is, the greater will be its refracting power; and of two refracting mediums of the ſame denſity, that which is of a fat or inflammable nature will have a greater refracting power than the other.

2. The angle of refraction depends on the obliquity of the rays falling on the refracting ſurface being ſuch always that the ſine of the incident angle is to the ſine of the refracted angle in a given proportion.

The incident angle is the angle made by a ray of light, and a line drawn perpendicular to the refracting ſurface at the point where the light enters the ſurface; and the refracted angle is the angle made by the ray in the refracting medium with the ſame perpendicular produced. The ſine of the angle is a line which ſerves to meaſure the angle, being drawn from a point in one leg perpendicular to the other.

In paſſing from a rare into a denſe medium, or from one denſe medium into a denſer medium, a ray of light is refracted towards the perpendicular; on the contrary, in paſſing from a denſe medium into a rare medium, or from one rare medium into a rarer, a ray of light is refracted from the perpendicular.

If the eye, therefore, is placed in a rarer medium, an object ſeen in a denſer medium, by a ray refracted in a plane ſurface, will appear larger than it really is, as things ſeem larger under water, to an eye in the air, than they do out of it, and the contrary *.

To theſe laws of refraction is to be attributed the difference between the real and the apparent riſing of the ſun, moon, and ſtars, above the horizon. The horizontal refraction is a little more than half a degree, whence the ſun and moon appear above the horizon when they are entirely below it. From the horizon the refraction continually decreaſes to the zenith. Refraction is increaſed by the denſity of the air, and conſequently it is greater in cold countries than in hot; and it is alſo affected by the degree of cold or heat in the ſame country.

On the principle of the refraction of light all dioptrical † inſtruments are conſtructed. As the greater the obliquity with which a ray ſtrikes a

* " As things ſeem large which we through miſts deſcry,
" Dulneſs is ever apt to magnify." POPE.

† Δια, *(dia,* " through") Gr. and οπτομαι, *(optomai)* " to ſee."

denſe

denſe tranſparent body the greater the refraction, it is evident that when a collection of rays paſs in a ſtrait line, and enter a body of any form approaching to that of a globe or ſphere, only one, viz. that which enters at its center, will enter in a direct line; all the reſt will ſtrike it more or leſs obliquely, and will all conſequently undergo a proportionable degree of refraction. As in a denſe body of ſuch a form the rays will be all refracted, converged, or bent inwards towards the centrical ray, there will be a point where they muſt all meet, and this point is called the focus. In this point they will therefore croſs each other, and diverge again in the ſame proportion, as it is the property of light conſtantly to proceed in a ſtrait line, whatever direction it takes. In paſſing through a glaſs or lens, which is equally convex on both ſides, the focus or point where the rays meet will be equal to the ſemidiameter of the glaſs's convexity, that is, half the diameter of that circle of which the convexity of the lens is an arch. As the rays croſs each other after they paſs the focus, it is evident that any image ſeen through a lens, beyond the focal diſtance, will be inverted, as may be proved by an eaſy experiment, *viz.* by holding a lens or magnifying glaſs between a candle and a ſheet of paper ſuſpended on the wall, at a proper diſtance, when the image of the candle will appear on the paper inverted; and the reaſon of this is extremely clear, for it is evident that the upper rays, after refraction, are thoſe which proceeded from the under part of the luminous body, and the under rays are thoſe which come from its top. The rays are therefore only inverted, and the image remains unimpaired.

Upon the ſame principles, if parallel rays paſs directly through a glaſs which is concave, they will diverge, or be bent outwards by the refractive power, exactly in proportion to the concavity, that is, in proportion to the obliquity with which they ſtrike on the glaſs; and the point of divergence, or negative or virtual focus, will be in the ſame proportion to the concavity of the glaſs as in the preceding inſtance. Converging rays, paſſing through a concave glâſs, will alſo be proportionally bent out of their courſe, and will not come to a point or focus ſo ſoon as they would otherwiſe have done.

In the middle part of the human eye, behind the pupil, there is placed a perfect convex lens, of a clear, tranſparent, jelly-like matter, which is called the cryſtalline humour; by this the rays of light are made to converge to a point, and croſs each other ſo as to form a ſmall inverted image of the object on the optic nerve, which is expanded on the back part of the eye, and called the retina. The apparent magnitude of objects will conſequently depend upon the ſize of the inverted image, or, in other words, upon the angle which the rays of light form by entering the eye from the extremities of any object; hence convex lenſes magnify, becauſe the rays proceeding from any object, and paſſing through the lens, being made to converge ſooner than they otherwiſe would, the angle is greater, and the object apparently

rently larger, or nearer, than when viewed by the naked eye; hence too a concave lens makes an object appear smaller, or more distant, because by its causing the rays of light to diverge, the visual angle is proportionably diminished.

Light is not only subject to the law of attraction, but to that of repulsion also; in other words, it is repelled, or REFLECTED, from all bodies which are not transparent. In reflection, light is still observed to proceed in strait lines, and the angle of reflection is equal to the angle of incidence; that is, when a ray of light strikes obliquely upon a mirror, it will be regularly returned with the same degree of obliquity with which it came; hence, when light is reflected from spherical bodies, the rays will converge or diverge as when it passes through bodies of a similar form, only that the effect will be reversed; hence rays reflected from a concave mirror, or speculum, will converge to a focus, the distance of which is in proportion to the concavity of the mirror.

By concentrating the rays of light, or, more properly speaking, by causing them to converge to a focus, heat is produced; hence every convex lens, and every concave mirror, is a burning glass, and the focal point is that in which the heat is most powerful.

Light is, however, not so simple a substance as it may be supposed upon superficially considering its general effects; it is indeed found to consist of particles which are differently refrangible, that is, some of them may be refracted more than others in paſſing through certain mediums, whence they are ſuppoſed by philoſophers to be different in ſize. The common optical inſtrument, called a priſm, is a triangular piece of glaſs, through which, if a pencil or collection of rays is made to paſs, it is found that the rays do not proceed parallel to each other on their emergence, but produce on an oppoſite wall, or any plain ſurface that receives them, an oblong ſpectrum, which is variouſly coloured, and it conſequently follows, that ſome of the rays or particles are more refrangible than others.

The ſpectrum thus formed is, perhaps, the moſt beautiful object which any of the experiments of philoſophy preſent to our view. The lower part, which conſiſts of the leaſt refrangible rays, is of a lively red, which, higher up, by inſenſible gradations, becomes an orange; the orange, in the ſame manner, is ſucceeded by a yellow; the yellow, by a green; the green, by a blue; after which follows a deep blue or indigo; and laſtly, a faint violet.

In the ſucceeding chapters I ſhall treat of the reflection and refraction of light in a more particular and ſcientific manner; but as the ſubject is ſomewhat abſtruſe, theſe preliminary obſervations appeared neceſſary, in order to render it more eaſy and intelligible to the general reader.

CHAP.

Chap. III.

OF THE REFLECTION OF LIGHT.

Angle of Reflection equal to the Angle of Incidence.—Reflection from plane Surfaces.—From ſpherical Surfaces.—Explanation of the Phenomena of concave Mirrors.—Of the projecting Figure which appears from them before the Glaſs.—Uſe of convex Mirrors to Travellers.

IT has been already proved, that the rays of light proceeding from any luminous body always move in *ſtrait* lines, unleſs this direction or motion is changed or deſtroyed by certain circumſtances *, which are now more particularly to be conſidered. The direction is changed by reflection, refraction, and inflection; the motion is deſtroyed by abſorption. It will be moſt conſiſtent with a lucid order, firſt to examine the nature of reflection.

A common experiment of children with a piece of glaſs oppoſed to the ſun, and caſting the light into various places at will, ſhews that the rays of light may be reflected by certain bodies, and by more accurate experiments it is found, that when a

* This is the principle on which all the reaſoning with reſpect to optics depends, and it is upon this principle that all the lines and figures referred to in the following pages are drawn.

ray

ray of light is reflected by any surface, the angle of incidence is equal to the angle of reflection. By the angle of incidence is meant, the angle made by the ray of light with a perpendicular to the reflecting surface at the point on which the ray falls; and by the angle of reflection, the angle which the ray makes with the same perpendicular on the other side. Thus, let Q, Plate I. Fig. 1. be a point from which rays diverging fall on the reflecting surface A B, and let Q D, Q E be two incident rays. At D, E draw the perpendiculars D C, E F to A B, and make the angles C D G, H E F equal to Q D C, Q E F, and the rays Q D, Q E will be reflected by the surface in the directions D G, E H.

Since no surface has hitherto been found so perfectly smooth, that it has not some inequalities in it to be discovered by a microscope, and yet these inequalities do not affect the law thus discovered for reflected rays, it is generally concluded, that the power which produces this change in the direction of the rays, acts at some small distance from the surface. The point Q, from which the rays diverge, is called the focus of diverging rays; and as, after reflection, the rays appear to have diverged from a point behind the surface, that point is called the focus of reflected rays. To find this point, produce the lines G D, H E till they meet the perpendicular drawn from Q on the reflecting surface produced, if necessary. Let Q M *q* be this perpendicular, which G D meets in *q*; then, since Q D C is equal

equal to GDC, QDM is equal to GDB but GDB is equal to MD*q*; in the two triangles QDM, MD*q*, there are two angles in the one equal to two angles in the other, and one ſide MD common to both, therefore QM will be equal to M*q*. The ſame may be proved alſo of the interſection of the lines HE*q* and QM*q*. Therefore the focus of rays reflected by a plane ſurface is at the ſame diſtance behind the ſurface, as the focus of diverging rays is before it *.

If, inſtead of rays diverging from one point they diverge from ſeveral, the correſponding foci will be found in the ſame manner. Let QR, Fig. 2, be a ſurface, from every point of which draw perpendiculars to the reflecting ſurface as before, and *qr* will be the image of QR, or all the rays diverging from QR will, after reflection, appear to have diverged from *qr*.

Every object placed before a reflecting ſurface has its correſponding image. If the object is a plane ſurface, the image will alſo be a ſimilar plane ſurface; if the object is a curvilinear ſurface, the image will correſpond to it; and in all caſes it is found in this manner, by perpendiculars drawn from the object to the reflecting ſurface, or the reflecting ſurface produced.

* To the general reader, who has no previous acquaintance with philoſophy, a part of this chapter will appear intricate and difficult. Let it be remembered, however, that it embraces ſome of the moſt difficult problems in natural ſcience, which, however, could not be omitted, and they are rendered as plain as the nature of the ſubject would admit.

To

To ſee any object, the eye muſt be ſo placed that ſome of the rays of light diverging from the object may fall upon the eye; and if, by looking upon a reflecting ſurface we ſee an image, we ſhould, if our judgment had not been corrected by experience, conceive an object to be placed behind the ſurface from which theſe rays diverged. Now, as an object may be placed in ſuch a ſituation before the reflecting ſurface that no rays can be reflected to our eyes, we ſhall not always ſee an object by reflection, and the places of the object, the ſpectator, and the reflecting ſurface, muſt be taken into conſideration. Let Q R be an object before the reflecting ſurface A B, *q r* its image, as before, Fig. 2, and O the place of the ſpectator. Join O A, O B, and produce the lines O A, O B indefinitely to T and P, unleſs the image lies within the lines A T, B P the object will not be ſeen by reflection. Let *f g* without this ſpace be the image of F G, and join O *f* O *g*, and ſince theſe two lines do not any where cut the reflecting ſurface, it is evident that by looking on the ſurface we ſhall not ſee the object. We ſhall ſee part of Q R, becauſe part of *q r* lies within the ſpace abovementioned, and to find the part of Q R which is viſible by reflection from the point *s*, where O P cuts *q r*, draw *s* S perpendicular to A B produced. Then the ray S B will be reflected in the direction B O. Now join O *q* cutting A B in D, and join Q D. The ray Q D will be reflected in the direction D O, and the part of the object viſible by reflection will be ſeen in part of the reflecting ſurface only

only D B. All the reft being fuperfluous as to this object. Thus we can always find by what rays, and by what part of a reflecting furface, an object is feen. The limits of the fpace in which an object muft be placed to appear vifible by reflection are, on thefe principles, eafily determined. Join O B, O A, and make the angles I B K, L A E equal to O B I, O A L, then every object placed within the lines B K, A E indefinitely produced, will be vifible at O by reflection.

Thus, when we are placed before a looking-glafs in a room, part of the room only is vifible; as we walk backwards and forwards other parts appear and difappear in fucceffion, and fome parts of the room are never feen in the glafs.

When a perfon ftands before a looking-glafs of the fame dimenfions with himfelf, his image appears to occupy the half of it, or, in other words, a looking-glafs of half his dimenfions is capable of fhewing him the whole of his figure. Let A B, Fig. 3. be an object placed before the reflecting furface *g h i* of the plane mirror C D; and let the eye be at *o*. Let A *h* be a ray of light flowing from the top A of the object, and falling upon the mirror at *h*: and *h m* be a perpendicular to the furface of the mirror at *h*, the ray A *h* will be reflected from the mirror to the eye at *o*, making an angle *m h o* equal to the angle A *h m*: then will the top of the image E appear to the eye in the direction of the reflected ray *o h* produced to E, where the right line A *p* E, from the top of the object, cuts the right line *o h* E, at E. Let B *i* be be a ray of light proceeding from the foot of the object at B to the mirror at *i*, and *n i* a perpendicular to the mirror from the point *i*, where the ray B *i* falls upon it: this ray will be reflected in the line *i o*, making an angle *n i o*, equal to the angle B *i n*, with that perpendicular, and entering the eye at *o*: then will the foot F of the image appear in the direction of the reflected ray *o i*, produced to F, where the right line B F cuts the reflected ray produced to F. All the other rays that flow from the intermediate points of the object A B, and fall upon the mirror between *h* and *i*, will be reflected to the eye at *o*; and all the intermediate points of the image E F will appear to the eye in the direction-line of these reflected rays produced. But all the rays that flow from the object, and fall upon the mirror above *h*, will be reflected back above the eye at *o*; and all the rays that flow from the object, and fall upon the mirror below *i*, will be reflected back below the eye at *o*: so that none of the rays that fall above *h*, or below *i*, can be reflected to the eye at *o*; and the distance between *h* and *i* is equal to half the length of the object A B, if the eye, or *o*, is in the line A B produced, for then A *h* will be equal to *h o*, and A *h* is equal to *h* E. Therefore *h* E is equal to *o h*, and *o h* is one half of *o* E, and consequently *i h* (from similar triangles) is equal to one half of E F or A B.

In rooms where looking-glasses are placed parallel and opposite to each other, a person looking into one sees several images of himself; for rays

4 will

Fig. 1.

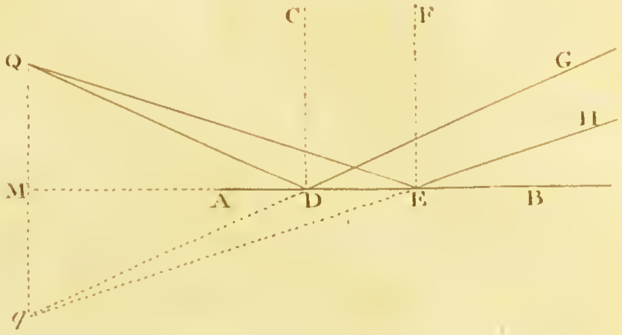


Fig. 2.

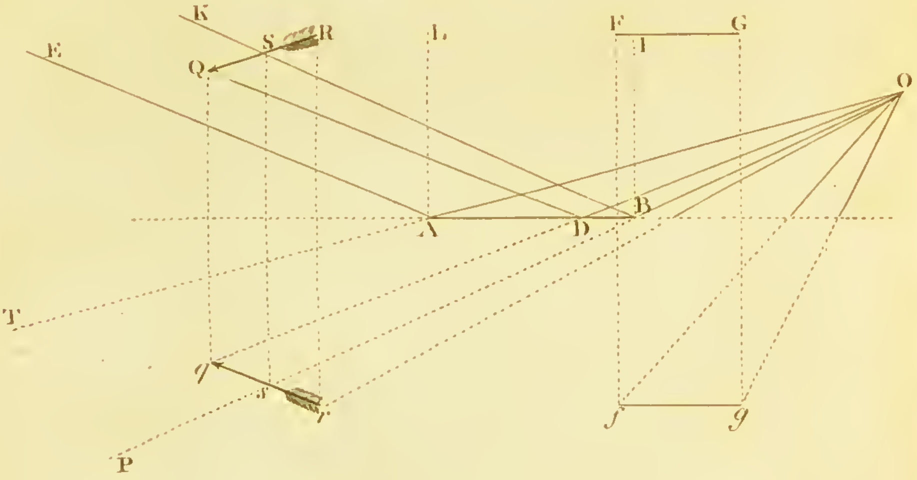
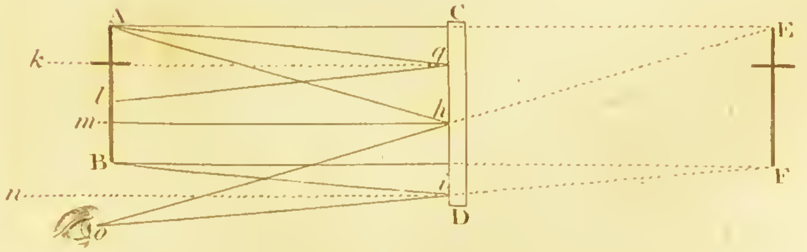


Fig 3



will be reflected from one glass to the other, and each image becomes an object to the other glass. If, instead of being parallel, the glasses were placed opposite to each other, but making an acute angle, there will be several images of the same object appearing to be placed in a circle, whose centre is the vertex of the acute angle, and radius the distance of the object from that vertex. Let M N O P Plate II. (Fig. 4.) two surfaces produced, meet in *b*, and let Q be an object, and *q*, *c* its images in the respective glasses. Join *b q*, *b* Q, and the triangles Q *a b*, *q a b*, having two sides and an angle respectively equal, the third side Q *b* is equal to *q b*. So *b c* is equal to *b* Q; and in the same manner the images of *q*, and *c* found in the opposite glasses, will be equidistant from *b*.

The places of images, made by the reflection of the rays of light from plane surfaces, are easily determined: but when rays are reflected by curvilinear surfaces, the difficulty of determining the place of the image is considerably increased. I shall endeavour to shew the manner of investigating this subject in the simplest cases.

Let A B (Fig. 5.) be a spherical surface, of which C is the centre, reflecting the rays of light both on the concave and convex side; and let Q E, a ray of light parallel to the radius C D, be incident on the surface at E. After reflection on the concave side, the ray will proceed in the direction E*q*, making the angle *q* E C equal to Q E C; but the ray Q E reflected by the convex surface

surface will proceed in the direction E K, making the angle K E I equal to the angle Q E I. The greater the distance of E, the point of incidence, is from D, the vertex of the surface, the farther will the intersection of the reflected ray of radius C D be from the center of the surface. Since Q E is parallel to C D, the angle Q E C is equal to the angle E C *q*; therefore the angles *q* E C, *q* C E are equal to each other, and consequently *q* C is equal to *q* E. If E is very near to D, *q* D and *q* E will be very nearly equal to each other, and the point *q* will then be very near to T, the point bisecting the radius of the surface. The parallel rays then falling upon the concave surface very near to D will converge, after reflection, very nearly to the point T, and that point may be considered, and is considered, as the focus after reflection of those rays; the aberration of every other ray, or the distance *q* T shall be afterwards considered. The parallel rays falling on the convex side will also, after reflection, appear to have diverged from this point, T, without any very material error. We may lay it down, therefore, as a principle, that rays falling upon a reflecting surface will, by the concave side, be made to converge to a point bisecting a radius drawn parallel to them, and by the convex side will be reflected so as to appear to diverge from a point bisecting the radius drawn parallel to them. This point, T, is called the focus; because, if the reflector is of sufficient magnitude, an inflammable object placed in that point may be set on fire by the

Fig. 4.

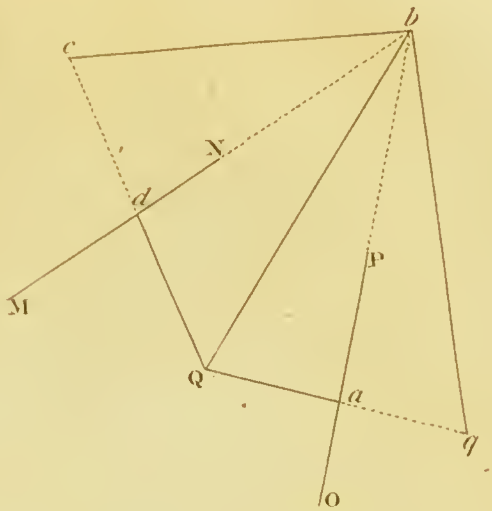


Fig. 5.

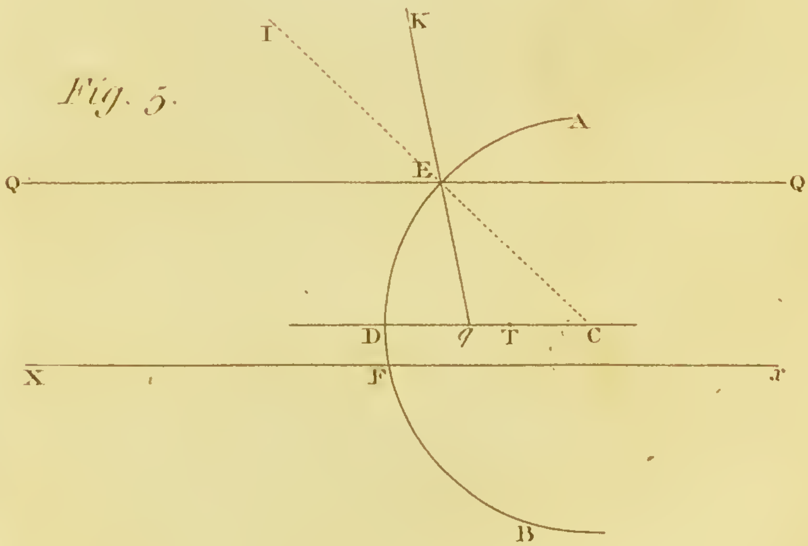
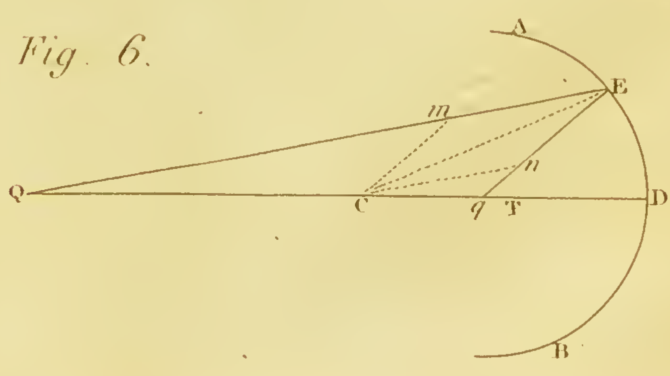


Fig. 6.



the reflected rays of the ſun from the concave ſurface; and it is ſuppoſed that a degree of heat may be excited by a concave reflector and the ſun's rays, greater than by any known application of artificial fire.

Let now (Fig. 6.) the rays diverging from a certain point be intercepted by a ſpherical reflecting ſurface, and let Q be that point, and A B the ſurface of which C is the center; and let *q* E be the reflected ray. Draw C *m* parallel to *q* E, and C *n* parallel to Q E. By the principle above mentioned a ray diverging from the point *m* will, after reflection, cut the parallel radius C *n* in *n*, biſecting the radius in that point; and, if a ray diverged from *n*, it will, after reflection, cut the parallel radius C *m* in *m*, biſecting that radius; therefore C *m*, C *n*, C T are equal. Since the triangles Q *m* C, C *n q* are ſimilar, Q *m* : *m* C, or C T : : C *n*, or C T : *n q*. The nearer E is to D, the nearer will the points *m* and *n* be to T; Q *m* will be nearly equal to Q T, and *q n* to *q* T. Therefore the focus of rays, after reflection, will be found, without very material error, by ſaying, as Q T : C T : : C T : T *q*. Calling therefore T the principal focus, its diſtance from the centre of the ſurface will be a mean proportional between its diſtances from the foci of diverging and reflected rays.

In Plate III. Fig. 7. the propoſition is in the ſame manner demonſtrated, by ſaying, that rays appearing to diverge from *m*, were reflected by the ſurface intercepting rays converging to *n*, and vice verſa.

The foci of diverging and reflected rays are always on the same side of the principal focus. The greater the distance of Q from T, the less is the distance of *q* from T; as Q approaches to T, *q* removes from it; they meet together when rays are reflected by a concave surface in the center. When the focus of diverging rays is between the center and the principal focus, the focus of reflected rays is on the other side of the center. When Q is in T, the reflected rays are parallel; when Q is between T and the surface, the rays appear to diverge from a point on the other side of the surface. When rays are reflected by the convex surface, the focus of the reflected rays is always between the principal focus and the surface.

Having found the focus of reflected rays for a single point, we can, as before, find the situation of the image of any object, by considering the object as made up of innumerable foci of diverging rays. Let QR (Fig. 8.) represent an object before a spherical reflector, then join Q C D, and in the line Q D find the point *q*, the focus of rays after reflection, by the proportion laid down in the preceding instance. In the same manner find the point *r*, and, if necessary, find the corresponding foci to other points in the object QR, then *q r* is its image. This image will be either erect or inverted, according to the nature of the reflector, and the position of the object. First, if the reflector is a spherical concave, as in Fig. 8, and the distance of the object from the surface is greater than half the radius of the reflector, the image will be inverted, and on the ſame ſide of the reflector with the object. If the diſtance of the object from the reflector is leſs than half the radius, the image will be erect, but on the other ſide of the reflector. This is ſeen in Fig. 9, where *q r* repreſents an object in the ſituation above-mentioned, and Q R is its image. 2dly, The image of an object before a convex ſpherical reflector is always erect, as may be ſeen in Fig. 9.

In plane reflectors images correſpond, and are ſimilar to their objects. It is not ſo in ſpherical reflectors, by which an image is made ſometimes greater, ſometimes ſmaller than the object. The concave reflector has the power of diminiſhing and magnifying. When the diſtance of the object from the reflector is greater that the radius, the image is always leſs than the object, for *q r* : Q R : : C *q* : C Q; and in that caſe C *q* being leſs than C Q, *q r* muſt be leſs than Q R. When the object is between the center and the principal focus, the image is greater than the object, for now *q r* being the object, Q R is its image, and C *q* being leſs than C Q, the object muſt be leſs than its image. When the object is between the principal focus and the reflector, the image is greater than the object; for ſuppoſing *q r* (Fig. 9.) to be the object, and Q R the image, *q r* : Q R : : T *q* : T Q; but T *q* being leſs than T Q, *q r* muſt be leſs than Q R. When an object is placed before a convex ſpherical reflector, the image is leſs than its object; for (Fig. 9.) T Q being greater than T *q*, Q R muſt be greater than *q r*.

To find whether an object may be ſeen in a reflector by a ſpectator in any ſituation, we draw lines from the eye to the image, and, if theſe lines are cut by the reflecting ſurface, the image is viſible, and the part of the reflecting ſurface intercepted between theſe lines is that part which reflects the rays to the eye. Let O be the eye of the ſpectator, Fig. 8; join O *q*, O *r*, and produce them, if neceſſary, till they cut the reflecting ſurface in *m* and *n*, then *m n* is the part of the reflecting ſurface in which the image is ſeen; and the rays Q *m*, R *n*, reflected in the direction *m* O, *n* O, are thoſe by which the extreme parts of the object are ſeen.

This would be ſtrictly true in all caſes, if rays proceeding from an object made it always viſible and clear; but we are accuſtomed from our infancy to determine on the nature and poſition of objects by rays diverging from them. To ſee, therefore, by reflected rays, they muſt appear to the eye to diverge from the image, which will not be the caſe when the eye is at a leſs diſtance from a concave reflector than the image. In that caſe our viſion is confuſed, the image is behind us, and we can form no conception of it. But this will be farther explained when I come to treat on the nature of viſion.

Upon the principles now laid down, we ſee the reaſon of thoſe beautiful and deformed images made by objects placed before ſpherical reflectors, as alſo the changes produced in them by their various poſitions with reſpect to the reflector. When a perſon

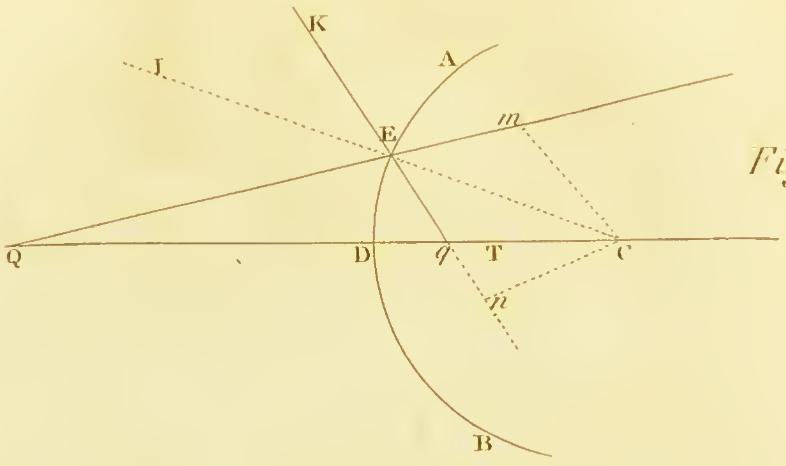


Fig. 7.

Fig. 8.

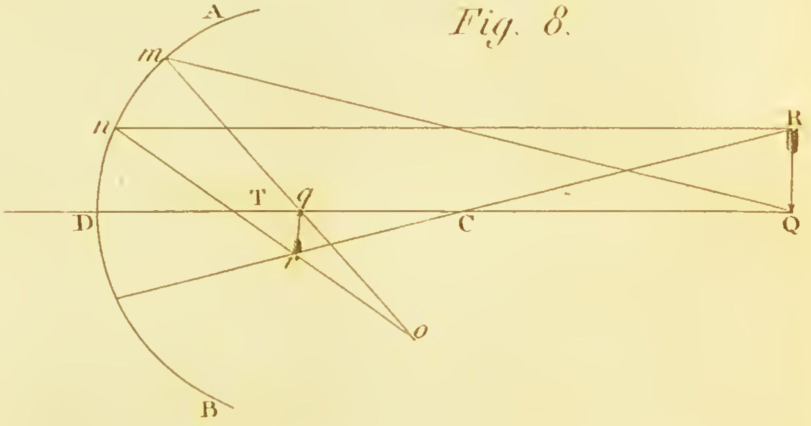
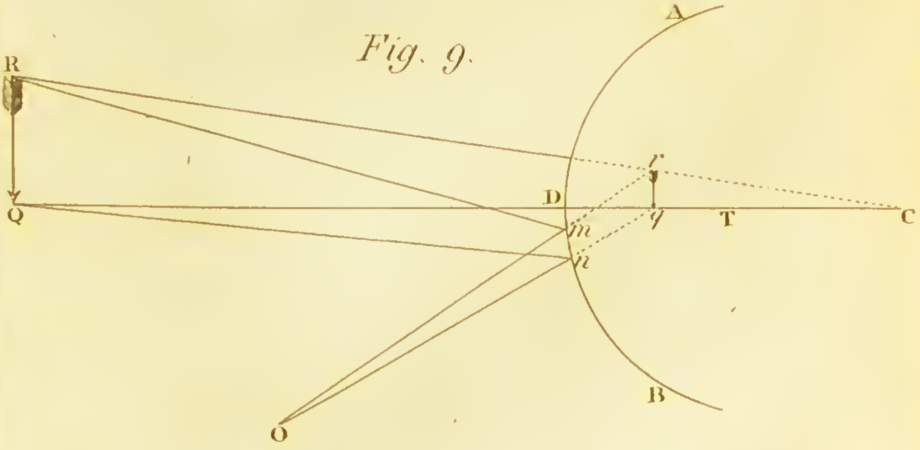


Fig. 9.



a perſon is at a greater diſtance from a concave ſpherical reflector than the radius, he perceives an image, for inſtance, of himſelf, much diminiſhed, ſtanding upon its head before the reflecting ſurface in the air; as he walks towards the center, the image walks towards him, increaſing in magnitude; as he walks from the center to the principal focus, his image appears confuſed, and he cannot aſcertain any of its parts; as he walks from the principal focus to the ſurface, the image is again clearly viſible, erect, greater than himſelf, but walking towards him, and diminiſhing conſtantly, till both object and image meet together in the reflecting ſurface.

From this property of the concave reflector to form the image of an object, in certain caſes, before the reflector, many deceptions have been produced, to the great ſurprize of the ignorant ſpectator. He is made to ſee a bottle half full of water inverted in the air without loſing a drop of its contents; as he advances into a room, he is tempted to exclaim with Macbeth, "Is this a dagger that I ſee before me!" and when he attempts to graſp it, it vaniſhes into the air.

A variety of ſimilar appearances may be repreſented, which are all produced by means of a concave reflector, having an object before it ſtrongly illuminated, care being taken that only the rays of light reflected from the object ſhall fall upon the concave reflector, placed in ſuch a manner that the image ſhall be in the middle of the adjoining room; or, if in the ſame room with the object and reflector, a ſcreen muſt be placed ſo as to prevent the ſpectator from diſcovering them. A hole is then made in the partition between the two rooms, or in the ſcreen, through which the rays paſs, by which the image is formed. The ſpectator then, when he caſts his eyes upon the partition or the ſcreen, will, in certain ſituations, receive the rays coming through this ſmall aperture. He will ſee the image formed in the air; he will have no idea, if not previouſly acquainted with optics, of the nature of the deception; and may either be amuſed, according to the inclination of his friends, with tempting fruit, or be terrified at the ſight of a ghaſtly apparition.

The phenomena of convex ſpeculums are different, and in moſt reſpects oppoſite, to thoſe of the concave ſpeculum. When a perſon looks in a convex ſpherical reflector, he ſees an image of himſelf, erect, but diminiſhed. As he walks towards the reflector, the image appears to walk towards him, conſtantly increaſing in magnitude, till they touch each other in the reflecting ſurface.

From this property of diminiſhing objects, ſpherical reflectors are in great requeſt with all lovers of pictureſque ſcenery. Small convex reflectors are made in the ſhops for the uſe of travellers, who, when fatigued by ſtretching the eye to alps towering on alps, can by their mirror bring theſe ſublime objects into a narrow compaſs, and gratify the ſight by pictures which the art of man in vain attempts to imitate.

CHAP.

CHAP. IV.

OF REFRACTION.

Refraction, what.—Law of Refraction.—Ratio of Refraction with respect to different Substances.—How the Situation of Objects is determined upon, seen through different Mediums.—How far the Situation of Objects is apparently altered by the Refraction of common Window Glass.—Refraction by spherical Surfaces.

BY experience we discovered that rays of light are reflected by many substances, and that the angle of reflection is equal to the angle of incidence: by experience, also, it has been discovered, that the direction of the rays of light is changed by their passage from one medium into another, and that this change of direction follows a determinate law. The space in which a ray of light moves, whether empty space, or space occupied by a peculiar substance, is called a medium; and in passing from pure space into any other medium whatever, or from any medium into a denser medium, a ray of light is bent towards the perpendicular on the surface separating the two mediums; in passing from a dense into a rarer medium, or from any medium into pure space, a ray of light is bent from this perpendicular; but a ray of light will only, in certain directions, pass out of a dense into a rarer medium; for when the angle is of a certain magnitude, determined by the nature of the mediums, the ray, inſtead of being refracted, will be reflected back into its original medium.

The law of refraction is, that the ſine of incidence is to the ſine of refraction in a given ratio, and this ratio is diſcovered by experience. Thus, when a ray paſſes out of air into water, the ratio is as 4 to 3.

out of water into air, as 3 to 4.
air into glaſs, as 3 to 2.
glaſs into air, as 2 to 3.
air into diamond, as 5 to 2.
diamond into air, as 2 to 5.

Let H F be a ray of light incident on the ſurface A B, (Plate IV. Fig. 10.) of a denſe medium A B C D, ſuppoſe it to be glaſs ſurrounded by air. Draw E F M perpendicular to A B, and make G F M ſuch an angle, that the ſine of H F E ſhall be to the ſine of M F G :: 3 : 2, and the ray H F will in the glaſs move in the direction G F. When the ray comes to G it ſuffers another change in its direction by moving into air, and to find this direction, draw I G N perpendicular to C D, and make L G N ſuch an angle, that the ſine of F G I ſhall be to the ſine of N G L :: 2 : 3, then the ray will move in the direction G L. Thus the whole progreſs of the ray is found to be in the direction H F G L, and by the ſame rule its progreſs through any number of mediums might be found.

The

The direction G L is parallel to the direction H F; for the angles M F G, F G I, N G K, are equal; and since the sine of M F G : sine of M F I : : sine of N G K : sine of N G L, the angles N G L, M F I, are equal, and consequently the angles N G L, N I O, are equal. Therefore the lines H O, G L, are parallel.

Let F G (Fig. 10.) be a ray in a dense medium incident on G, and its direction after emergence be G L. The greater the angle F G I is, the greater will be the angle N G L. Suppose N G L to be a right angle, then the sine of F G I : radius : : sine of incidence : sine of refraction, and according to the law of refraction for the given medium, the limiting angle of incidence will be found for a ray to emerge. When the angle of incidence is greater than this angle thus found, the incident ray will be reflected back, as *a b c*.

Let rays diverging from a point Q (Fig. 11, 12.) after refraction, move in the medium A B C D. To a person in this medium they will not appear to have diverged from Q, but from a point nearer to or farther off from him, according as the medium, in which he is, is denser, or rarer than the medium in which the point of diverging rays is situated. Let Q I be an incident ray proceeding after refraction in the direction I M, cutting Q O a perpendicular to the surface A B in *q*, *q* will be the point from which the rays appear to diverge. In the triangle Q I *q*, Q I : I *q* : : sine of

I *q* Q

I *q* O : ſine of I Q O ; that is, ſince Q O is parallel to I P : : ſine of refraction : ſine of incidence. If I is very near to O, the lines Q I, *q* I, will be very nearly equal to Q O and *q* O, and a perſon being placed in the direction Q O produced will conceive that the rays diverged from *q*, when Q O : *q* O : : ſine of refraction : ſine of incidence.

Upon this principle we can find the actual ſituation of any object ſeen in a medium different from that in which we are, or ſeen through different mediums. Let Q R (Fig. 13, 14.) be any object ſeen by a perſon in the medium A B C D. Then make Q E : *q* E and R F : *r* F : : ſine of refraction to the ſine of incidence, and the object will appear to be at *q r* nearly, if the perſon was in the direction Q E produced. Let O be the place of the perſon's eye in any other ſituation, and join O *r*, O *q*, then the object is ſeen by rays refracted within the ſurface *m n*, and Q *m* O, R *n* O, are the directions nearly of the extreme rays by which the object is viſible.

Hence we perceive the reaſon why the bottom of a river appears to us nearer than it really is; and why an oar, partly in and partly out of the water, ſeems broken. Let Q *m a* (Fig. 15.) repreſent an oar, the part *m* Q being out of, and the part *m a* being in the water, the rays diverging from *a* will appear to diverge from *b* nearer to the ſurface of the water, every point in *m a* will be found nearer to the ſurface than its real place, and the

part

part $m a$ will appear to make an angle with the part $Q m$.

On the same principle a common experiment is explained. Put a shilling into a bason, and walk back from it till the shilling is just obscured by the side of the bason; then by pouring water into the bason, the shilling appears instantly; for by what has been said above, the object, being now in a denser medium, is made to appear nearer to its surface.

As we are accustomed to see objects frequently through thin panes of glass, it may, to prevent misapprehensions on this subject, be necessary to shew what changes take place in the apparent situation of these objects from the intervention of such a medium.

Let ABCD (Fig. 15.) be a pane of glass, QR an object seen through it, whose apparent place, found by the preceding rules, is $x r$, and let $Q m o p$ represent the progress of one of the rays diverging from Q. Then, from what has been before observed, $x p$ is parallel to $Q m$. Therefore $q m : m o :: Q q : Q x$; that is, when m is very near to E,

$$q E : E F :: Q q : Q x;$$

$$\text{or, } q E : Q q :: E F : Q x.$$

But supposing $I : R$ to represent the ratio of the sines of incidence and refraction of a ray passing into the glass,

$$q E : Q q :: I : I - R,$$

$$\therefore E F : Q x :: I : I - R;$$

that

that is, the interval between the surfaces of the pane is to the distance between the real and apparent places of the object as the sine of incidence to the difference between the sines of incidence and refraction. For glass this ratio is nearly that of 3 : 2; therefore I : I — R : : 3 : 1, and Q *x* will be therefore one third of E F; if the pane of glass is a tenth of an inch thick, an object seen through it will not appear to be a thirtieth part of an inch out of its real place; a change which is too small to be taken notice of in common life.

A ray passing through a medium bound by plane surfaces inclined to each other, is bent towards the thicker or thinner part of the medium, according as the medium is denser or rarer than that by which it is surrounded, and the place in which an object will appear to be is found by a very easy construction. Let A B C (Plate V. Fig. 16.) be a glass prism, Q R an object seen through it by an observer at O. From Q draw Q H perpendicular to the first surface A C, and let *q* be the focus of rays refracted by that surface; from *q* draw *q* E perpendicular on A B, the second surface produced, if necessary, and supposing *q* then to be the focus of diverging rays falling on A B, let *t* be the focus of rays after refraction found by the proportion before laid down, or by joining H E, and drawing Q *t* parallel to it. In the same manner the apparent place of R will be found, and a person at O will see the object Q R apparently in *t x*. The point Q he sees by the

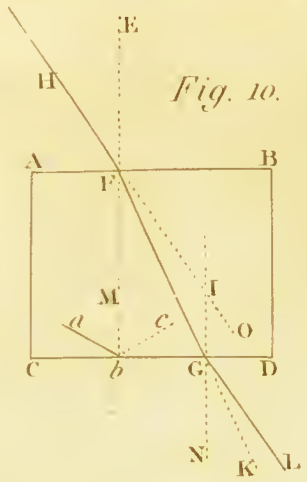


Fig. 10.

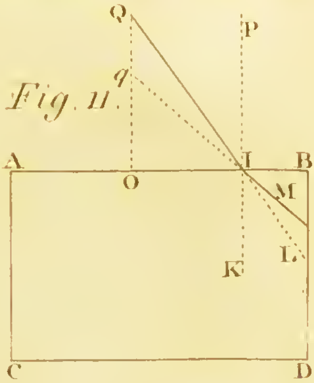


Fig. 11.

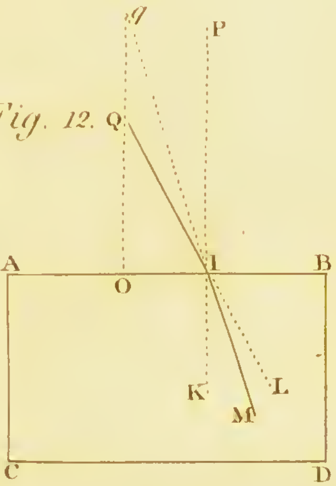


Fig. 12.

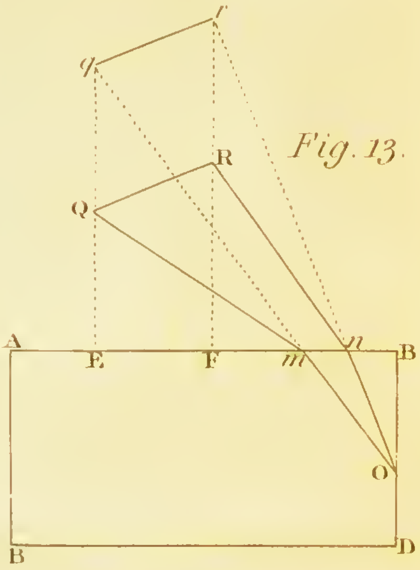


Fig. 13.

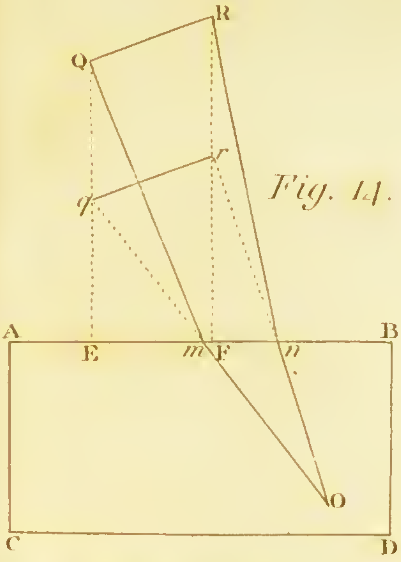


Fig. 14.

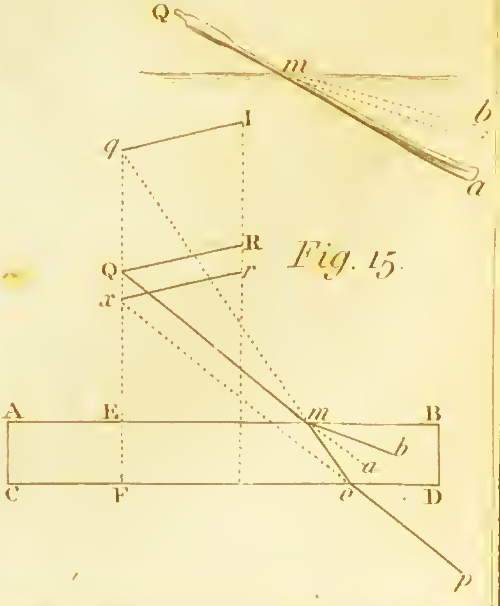


Fig. 15.

the ray Q F G O, and the point R by the ray R L M O.

When the surfaces are spherical, a change is made in the apparent places of objects no less remarkable than that which we have observed in objects placed before convex or concave mirrors. To understand the reason of these appearances, it is necessary to examine the progress of a ray in the simplest cases, and thence to go on to the more difficult.

Let A B F D (Fig. 17, 18.) represent a medium rarer or denser than the surrounding medium, and bounded by a spherical surface A E B, and let the ray G H parallel to I E a ray passing through the center of the arch A E B be refracted at H, to or from the perpendicular, according to the nature of the medium. The sine of the angle C H G is to the sine of the angle C H I in a given ratio, but C I : I H : : S. C H I : S. C H G, therefore I H : I C in the given ratio of the sine of incidence to the sine of refraction depending on the nature of the mediums. The nearer H is to E the nearer will the ratio of I H to I C be to that of I E : I C, and consequently by finding a point I in the line C E produced, such that I E may be to I C in the given ratio of the sine of incidence to the sine of refraction, all the rays parallel to I E, which are refracted by the convex surface A E B (Fig. 17.) will after refraction converge to I, or a small space very near it. The greater the distance of H from E, the greater will be the distance of of the intersection of the refracted ray and line IC from the points I and M. This point I is called the focus of refracted parallel rays.

In the same manner M is the focus of rays coming out of the dense medium, and C M : E M :: sine R : sine I.

Parallel rays incident on the convex surface of a denser medium, or the concave surface of a rarer medium (Fig. 17.) converge after refraction; and on the contrary, if they fall on the convex surface of a rarer, or the concave surface of a denser medium (Fig. 18.) they appear to diverge after refraction. The focus of parallel rays thus found is called the principal focus.

Let Q now (Plate VI. Fig. 19.) be the focus of diverging rays incident on the surface A B of a denser medium; to find the focus after refraction draw QI an incident ray, and suppose T to be the focus of rays parallel to C Q, incident on the concave surface IEB, and make C P equal to C T, from I draw I q parallel to C P, and q will be the focus of refracted rays. Let t be the focus of rays parallel to Q C incident on the convex surface, and make C p equal to C t. Then since a ray parallel to C p incident on the concave surface would after refraction converge to P, a ray diverging from P will after refraction go parallel to C P. Now the course of the ray QI is the same, whether it is considered as diverging from Q or P, therefore the direction of one of the rays diverging from Q will be in the line QIq. Suppose now the ray

q I

Fig. 16.

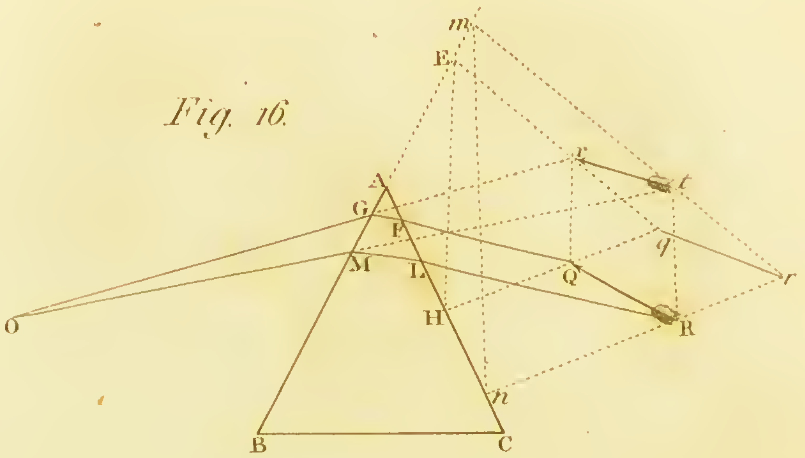


Fig. 17.

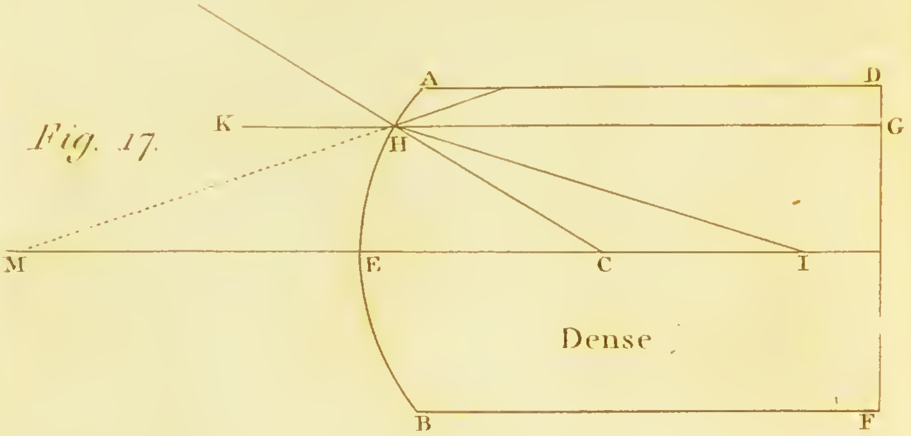
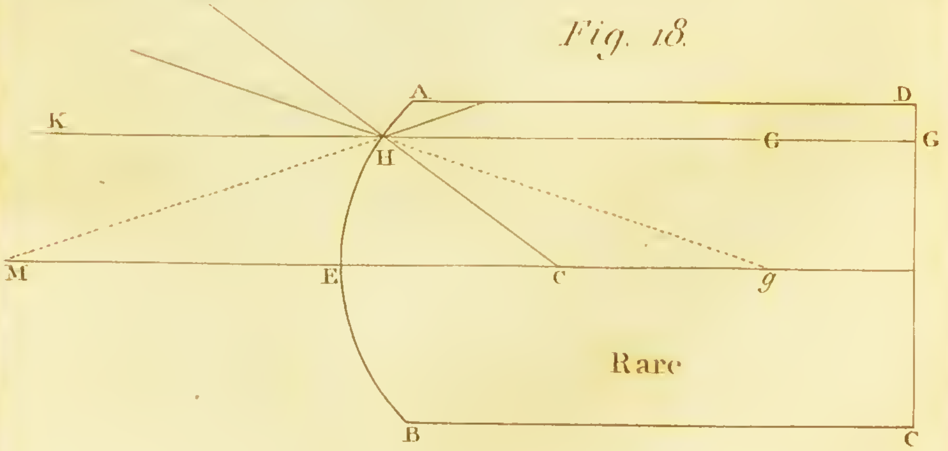


Fig. 18.



q I to be turned back, its progreſs will be the ſame as if it had diverged from *p*; but all rays diverging from *p*, and incident on the concave ſurface, move after refraction parallel to C *p*, *p* being the focus of parallel rays incident on the other ſurface, therefore the ray *p* I muſt after refraction move parallel to C *p*; but its direction muſt neceſſarily be I Q, therefore I Q is parallel to C *p*. We have hence two ſimilar triangles Q P C, C *pq* and Q P : P C : : C *p* : *pq*. Now if I is very near to E, Q P, P C, C *p*, *pq* will be very nearly equal to Q T, T C, C *t*, *t q*, and by making as Q T to T C, ſo C *t* to *t q*, we ſhall find a point *q* near to which all the rays diverging from Q will by refraction be made to converge.

Hence Q T varies inverſely as *t q*; that is, the greater the diſtance of Q from T, the leſs will be that of *q* from *t*, for C T and C *t*, remain invariable in the proportiòn, however the poſition of Q may be varied.

The points Q and *q* are always on oppoſite ſides of T and *t*.

If the point Q was at ſuch a diſtance, that the rays diverging from it might be conſidered as parallel, *q* and *t* would coincide. As Q was brought nearer to T, *q* would recede from *t*; when Q and T coincide, little *q* will be no longer in the line E *q*, but the refracted rays will now be parallel. As Q moves from T to E, *q* appears at a great diſtance from E on the ſame ſidè of the ſurface with Q and overtakes it at E.

Diverging

Diverging rays incident on the convex ſurface of a denſer medium, or the concave ſurface of a rarer medium, are made to converge or diverge according to the ſituation of their foci with reſpect to the principal focus. When they are incident on the convex ſurface of a rarer medium, or the concave ſurface of a denſer medium, their progreſs may be ſeen in Figures 20, 21.

The ray Q I diverging from Q will be affected in the ſame manner as if it was ſuppoſed to converge to P the principal focus of rays incident on the concave ſurface; but a ray converging to P, will by refraction of the convex ſurface be made to proceed in a direction parallel to C P, therefore q I will be parallel to C P. Again, a ray incident on concave ſurface converging to q, may be conſidered as converging to p, the focus of parallel rays on the convex ſurface, and therefore by refraction of the concave ſurface, it will be made to proceed in a direction parallel to C p. Hence as before the triangles Q P C, $q\,p$ C are ſimilar, and the ſame proportion is deduced Q T : T C :: t C : $t\,q$.

Rays therefore diverging from any point, and intercepted by the convex ſurface of a rarer or concave ſurface of a denſer medium will by refraction be made always to diverge more. Upon the ſame principles, and in the ſame manner, the effects of ſpherical ſurfaces on converging rays is ſhewn, which are exactly oppoſite to thoſe of diverging rays, and a learner may profitably exerciſe himſelf by trying the effect on paper on rays converging or diverging

Fig. 19.

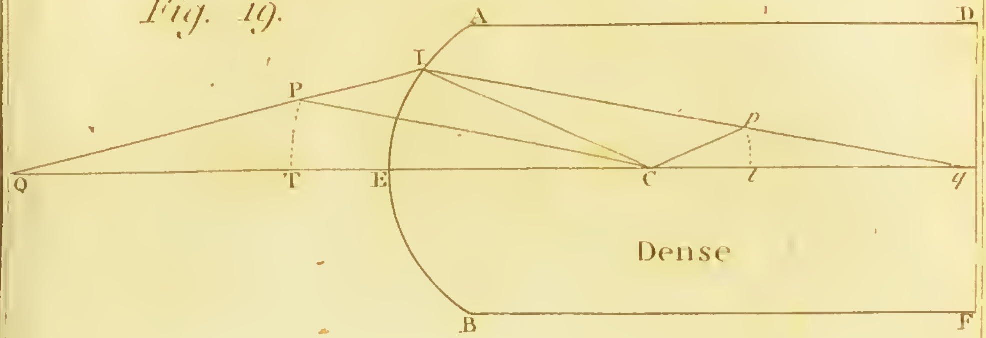


Fig. 20.

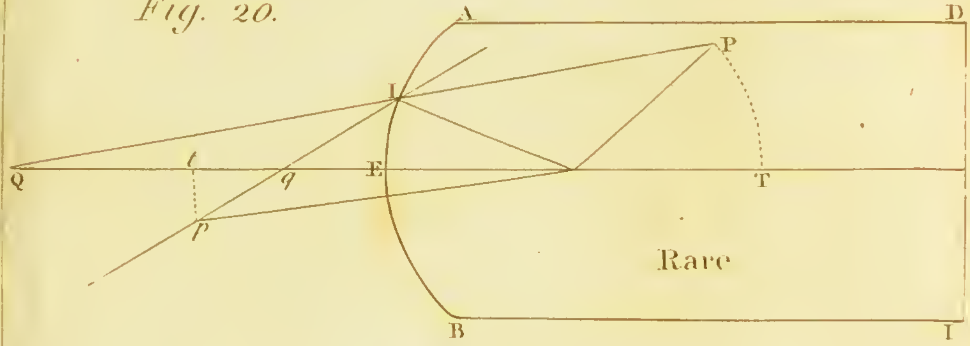
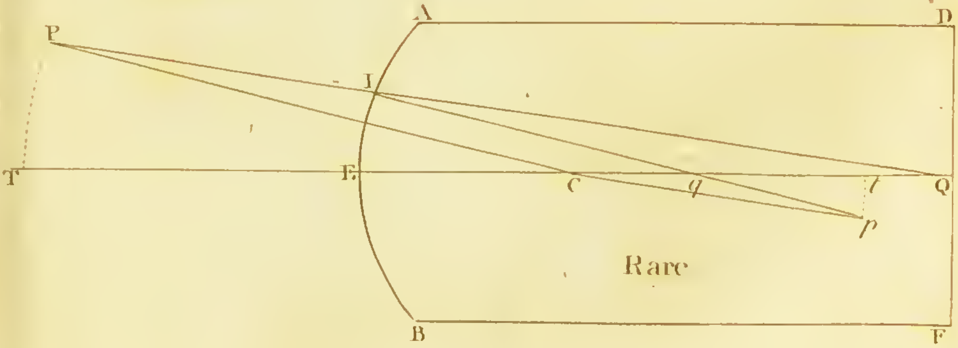


Fig. 21.



diverging, refracted by the convex or concave surface of different mediums.

Having thus discovered the progress of rays of light diverging from any point, and intercepted by a refracting spherical surface, we shall find no difficulty in accounting for the apparent places of objects seen in different mediums bounded by spherical surfaces.

Let QM (Plate VII. Fig. 22.) be an object in a glass medium, and *q* the focus of refracted rays diverging from Q, *m* the focus of refracted rays diverging from M. Then *q m* will be the image of QM. Let O be the place of the spectator, and join O *q*, O *m*, then *r s* is the part of the glass through which he sees the object, and Q *r* O, M *s* O are the extreme rays by which it is seen. Let a dense medium be now bounded by a convex surface, fig. 23. and an object QM be at such a distance from it, that its image shall be *q m*, and the place of the spectator O. He will see only part of the object corresponding to *u m*, and through the part of the surface A *s*, and the object will appear to him inverted.

If the eye is placed nearer the surface than the image is, the object will appear confused; for the rays striking the eye will then be converging to a place behind it: but as I have been rather prolix on this subject in the case of objects before reflecting mirrors, it will not be necessary to pursue it farther, as on the same principles the reader will with ease determine the part of an object seen in any medium, bounded by a ſpherical ſurface, the part of the ſurface through which it is ſeen, and the rays by which it is ſeen. The truth of ſome of theſe principles may be experimentally ſhewn by objects placed in glaſs veſſels, with concave or convex ſurfaces, filled with water, but as we cannot form a medium rarer than that in which we live, the caſes of objects placed in a rarer medium muſt remain eſtabliſhed on the fixed baſis of mathematical truth here laid down. If we were indeed to rarify the air in a hollow glaſs globe, we might obſerve, perhaps, the changes made in the apparent places of an object, according to the ſucceſſive degrees of rarefaction; but ſtill the object would be ſeen through one medium much denſer than the ſurrounding atmoſphere, and before we can examine the apparent ſituation of an object placed in one medium, which is ſeparated from another by a medium of a different denſity from either, and bounded by a concave and convex ſurface, we muſt endeavour to account for the appearances which are daily before our eyes, namely, the changes made in the apparent places of objects by the interpoſition of a denſe ſubſtance bounded by ſpherical ſurfaces.

CHAP. V.

OF LENSES.

Glaſſes uſed to correct and aſſiſt the Sight.—Different Forms of Lenſes.—Effects reſulting from theſe different Forms.—Double convex and concave Lenſes.—Plano-convex and concave Lenſes.—How to determine the Focus of a Lens.—Focus of Rays diverging from a Point, and intercepted by a Lens.—Focus of a Sphere.

IN common life, perſons whoſe ſight is bad make uſe of glaſſes to correct the defect in their eyes, and theſe are in general thin pieces of glaſs, the ſurfaces of which are both concave, or both convex, and equal ſegments of a ſphere. Such a glaſs, we have already ſeen, is called a lens, which is not, however, confined to theſe two ſhapes; for ſome have one ſurface plane and the other concave, ſome have one ſurface plane and the other convex, others have one ſurface concave and the other convex; but the properties of all theſe glaſſes will be eaſily underſtood by any perſon who has duly conſidered the effect of a ſingle ſpherical refracting ſurface on the rays of light.

It is neceſſary to premiſe, however, that in inveſtigating the properties of a lens, we conſider its thickneſs as very inconſiderable, and that in every ſpecies there is a point, through which if a line is drawn in any direction, and interſected by the ſurfaces of the lens, a ray refracted by one ſurface into this line will, after the ſecond refraction, emerge parallel to its firſt direction.

Let A I *o* B *n* (Plate VII. Fig. 24, 25.) repreſent a convex or concave lens, the radii of whoſe ſurfaces are equal, and draw C I, C *i* from the centers C, *c*, parallel to each other, and join I *i*. Suppoſe now I *i* to be a ray of light within the lens refracted by both ſurfaces at I and *i*. Since the radii are parallel, the angles of incidence are equal, and conſequently the angles of refraction are equal, and the refracted rays muſt make equal angles with the incident ray I *i*, that is, they muſt be parallel to each other. A ray, therefore, incident on I, and proceeding in the direction I *i*, will, after refraction at *i*, proceed in a direction parallel to its firſt direction. In the ſame manner any other ray incident on one ſurface, and proceeding in the line joining two parallel radii, will, after refraction at the ſecond ſurface, emerge parallel to its firſt direction. But the line joining two parallel radii will always paſs through the ſame point *m*; therefore all rays paſſing through this point *m* will, after refraction at the ſecond ſurface, proceed parallel to the direction, which they had before the firſt refraction. This point *m* is the center of the lens, and in the two caſes before us it biſects the thickneſs of the lens; for ſince the triangles C I *m*, *c i m* are ſimilar, C I : *c i* : : C *m* : *c m* and as C I and *c i* are equal C *m* and *c m* are equal,

and

Fig. 22.

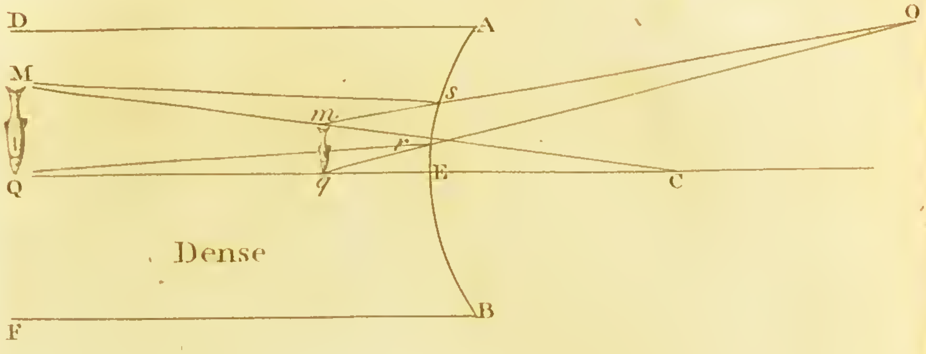


Fig. 23.

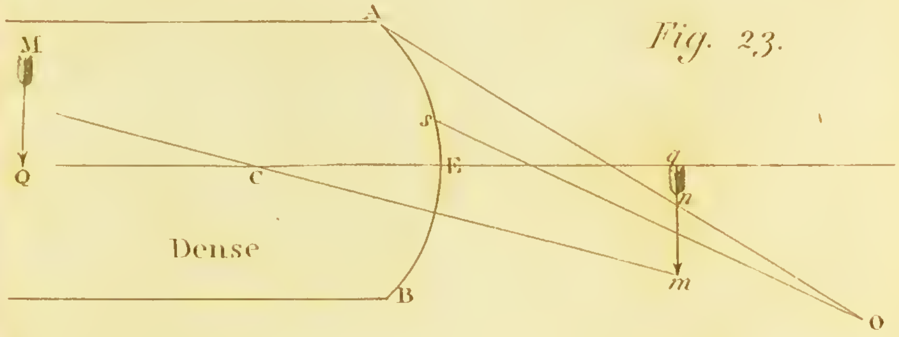


Fig. 24.

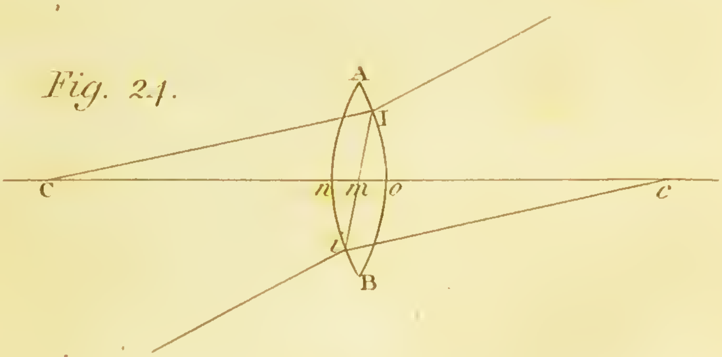
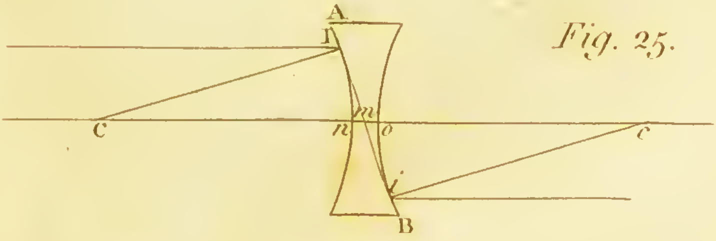


Fig. 25.



and conſequently *n m* and *m o* are equal. If the radii were not equal, the center of the lens is neareſt to that ſurface whoſe radius is the leaſt, and its place may be accurately found by the preceding proportion.

In Plate VIII. Fig. 26, 27. repreſent two lenſes, the one with a plane and a convex ſurface, the other with a plane and a concave ſurface. In both caſes the center of the lens will be at *n* in the ſpherical ſurface, for the point may be conſidered as in the tangent to the circle at *n*, which is parallel to A I B, therefore the ray I *i* makes equal angles of incidence at the points I and *i*, and conſequently the angles of refraction will be equal. From the proportion alſo diſcovered in convex or concave lenſes, the ſame truth is evident; for as we increaſe the radius of A I B, the point *m* approaches nearer to *n*; and as this radius may be increaſed without limit, the diſtance of *m n* may be decreaſed without limit, ſo that evidently the nearer the circle approaches to a plane figure, the nearer will be the approach of *m* to *n*,

Plate VIII. Fig. 28. repreſents a lens with one ſurface concave the other convex, in which caſe the point *m* will be without the lens.

Having found the centre of a lens, we are next to find its principal focus or point, from which parallel rays, after refraction, appear to diverge, or to which they converge. Let A B (Plates VIII. IX. Fig. 29, 30, 31, 32, 33, 34) repreſent a lens, whoſe center is E, and the centers of the ſurfaces R and *r*, and let *q* E G be drawn parallel to the incident rays; then as the directions before and after refraction of a ray paſſing through the center of a lens are parallel, *q* E G will repreſent the courſe of one of the incident rays without ſenſible error. Parallel to E G draw B R, and in B R produced find the focus V of parallel rays incident on the ſurface B; therefore by the firſt refraction the parallel rays are made to ſtrike the ſecond ſurface A, converging to the point V. Join *r* V. Then one of the rays, which after the firſt refraction moved within the glaſs in the direction *r* A, will paſs through the ſecond ſurface A, without any refraction, in the direction AV, ſince *r* A is perpendicular to the ſecond ſurface. But E G is the courſe of another ray alſo after the ſecond refraction, and G, the point of interſection of theſe two rays, will be the focus of the lens, near to which all the other rays will interſect each other. For all the rays incident on the ſecond ſurface converging to the point V, by what has been proved of rays refracted by a ſingle ſpherical ſurface, will be made to converge to a point between A and V. We have found the point G, as above, for a double convex lens, but the ſame mode of reaſoning applies to other lenſes, and a ſingle inſpection of the figure will ſhew whether the rays converge or diverge after the firſt refraction.

With E as a center, and E G as radius, deſcribe the arc G F. Then if the direction of the parallel rays is changed, the focus will always be in the arc G F, and if the incident rays are parallel to *r* R, the

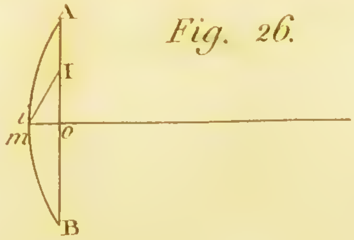


Fig. 26.

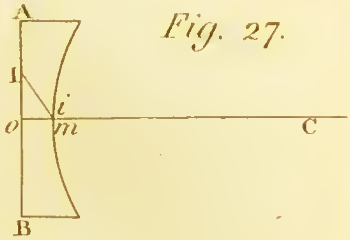


Fig. 27.

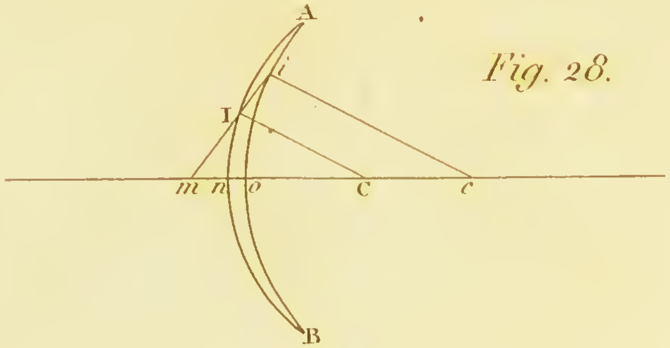


Fig. 28.

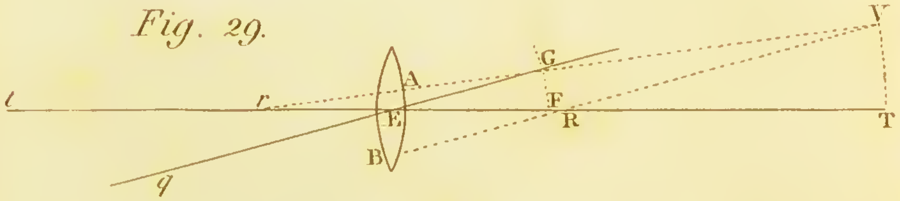


Fig. 29.

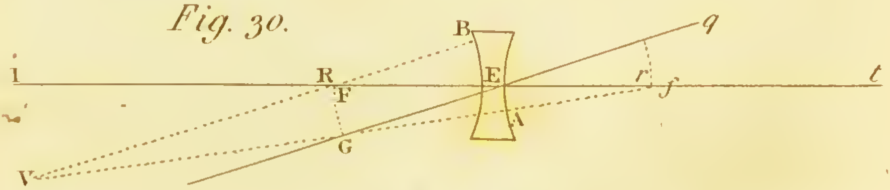


Fig. 30.

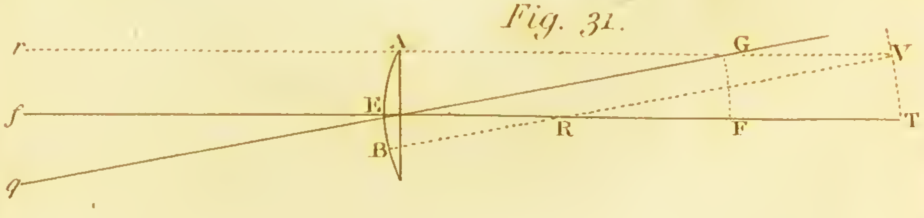


Fig. 31.

the axis of the lens, the principal focus is in F. A double convex and plane convex lens make parallel rays to converge; a double concave and plane concave make them diverge. A lens with a concave and convex ſurface make them converge or diverge, according as the ſurfaces do or do not interſect each other, or in general it may be ſaid of all theſe lenſes, that the parallel rays converge or diverge after refraction according as the middle of the glaſs is thicker or thinner than its extremities.

Upon the ſame principles alſo may be found the foci of lenſes, ſuppoſing them to be compoſed of ſubſtances rarer inſtead of denſer than the ſurrounding medium.

Having found the principal focus of a lens, we ſhall with the ſame eaſe find the focus of rays diverging from a point, and intercepted by a lens, as we did when they were intercepted by a ſingle ſurface. Let Q (Plate IX. Fig. 35.) be the focus of diverging rays incident on the lens A B, and let F, *f*, be the principal foci of rays incident on the ſurfaces B or A, in a contrary direction, and let Q *i* repreſent an incident ray. With E as a center, and E F radius, deſcribe the arc F G interſecting Q *i* in G, join E G, and draw A *q* parallel to E G, then with E as a center, and E *f* radius, deſcribe the arc *f g* interſecting *i q* in *g*, and join E *q*. The ray Q *i* will be affected in the ſame manner, whether it is conſidered as diverging from Q or G; but ſince rays parallel to E G, incident on the ſurface B, are by the refraction of the lens made to converge to G, a ray diverging from G will, after the refraction of the lens, move parallel to E G; therefore the ray Q *i* will be made by the lens to move in the direction A *q*. Again, if the ray was turned back, it might be confidered as diverging from *g*, and by the lens it would be made to move in the direction *i* Q, parallel to E *q*. Hence we have two triangles, Q G E, E G *q*, fimilar to each other, and Q G : G E : : E *g* : *g q*; that is, the nearer *i* is to E, the nearer will this proportion be to that of Q F : F E : : E *f* : *f q*, a proportion fimilar to that which we found before with fingle furfaces.

The points Q and *q* will be on the oppofite fides of their refpective foci. The greater Q F is, the lefs will be *q f*, and *vice verfa*; and the apparent places of objects viewed through thefe glaffes will be found in the fame manner as with fingle furfaces. It will be fufficient therefore only to refer the reader to Plates IX. X. Fig. 36, 37. which he will eafily underftand without farther explanation.

The principal focus of a fphere is found with the fame facility as that of a lens. Let M (Plate X. Fig. 38.) be the principal focus of rays incident on the convex furface A O, then bifect M D, in I, and I will be the principal focus of the fphere. For let the ray G A be refracted by the convex furface to B, and at B by the concave furface to I, and let I B, G A produced meet each other in K. Now fuppofe that the ray A B within the fphere emerged at both places A and B, then fince the

angles

Fig. 32.

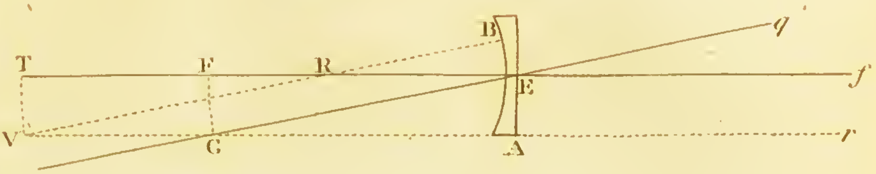


Fig. 33.

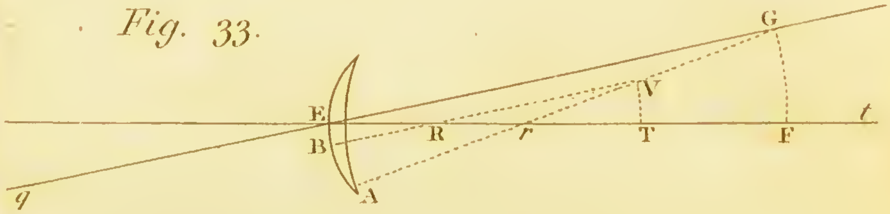


Fig. 34.

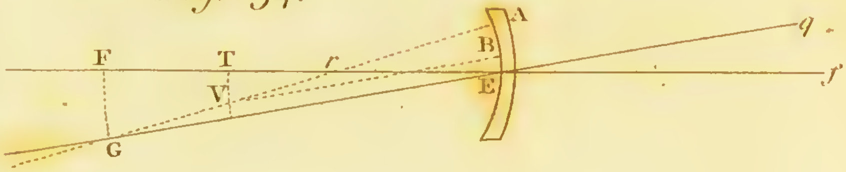


Fig. 35.

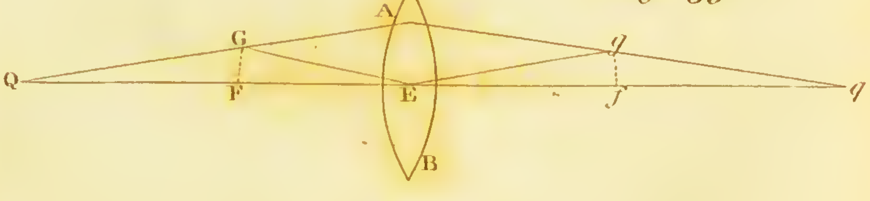
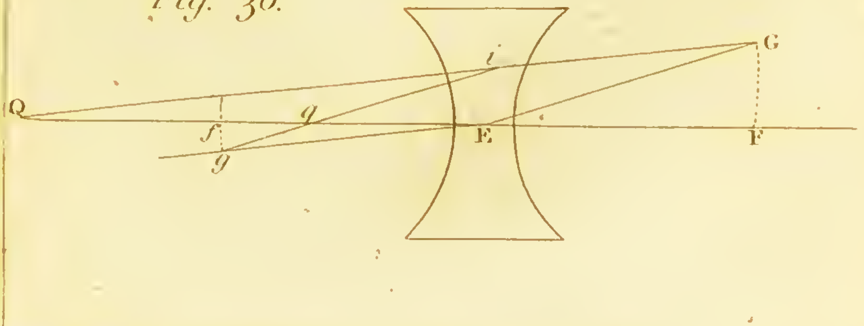


Fig. 36.



angles of incidence C A B, C B A are equal, the angles of refraction, and the difference between the angles of incidence and refraction, will be equal; therefore K A B is equal to K B A, and K A equal to K B; but the triangle B I M is similar to the triangle K B A, therefore I B is equal to I M; and as B approaches to D, the nearer will I B be equal to I D, that is, I D to I M, and consequently the principal focus will bisect D M, or the least distance of the principal focus of rays refracted by the convex surface from the sphere.

Having thus found the principal focus of the sphere, I shall leave the reader to find the apparent places of objects seen through it, as the mode to be pursued has already been sufficiently described, and the proportion is similar to that discovered in the consideration of lenses.

Chap. VI.

OF VISION AND OPTICAL GLASSES.

The Eye described as an optical Instrument.—Defects of the Eye.—Short and weak Sight.—The former remedied by double concave, and the latter by double convex. Glasses.—How the Faculty of seeing correctly is acquired.—Apparent Magnitude depends on the Distance of Objects.—Visual Angle.—In what Manner Glasses assist the Sight.

THE structure of the eye will be considered in another place *; it will be sufficient therefore at present to treat it as a simple lens, which has the power of refracting the rays of light, incident upon it, on the retina, whence we derive all our ideas of sight, and by repeated experience correct the errors which by that organ alone might have been produced. Let A B (Plate X. Fig. 39.) represent a section of the eye, M N being the pupil, A q p B the retina or optic nerve expanded over the internal surface of the eye, and let qp be the image of Q P made by the lens M N. The action produced on the part of the retina qp occasions a sensation, from which we derive by the sight our knowledge of external objects.

* See Book IX. Chap. 41. Sense of Sight.

Now

Now if the lens MN was fixed, the image of two objects at different diſtances from the eye would not fall on the retina, and therefore it is wiſely provided by our Creator, that we ſhould have the power of adapting the lens to the diſtance of the object, ſo that its image ſhould be always upon the retina. This is the caſe with the generality of mankind; but all perſons have not this power; for the eyes of ſome are ſo conſtructed, that the rays of light either converge too ſoon or too late; that is, the image is made in ſome place between the retina and the pupil, or it would be made behind the retina, if the retina was removed; hence theſe perſons cannot ſee objects diſtinctly, and to remedy theſe defects glaſſes are uſed, which in the one caſe make the rays diverge, and in the other caſe make them converge. Thus for ſhort-ſighted perſons as they are called, double concave glaſſes, for long-ſighted perſons, double convex glaſſes are uſed. By means of the concave glaſſes, the rays incident on the eye are made to diverge more; and conſequently the eye, which before made them converge too ſoon, will now be able to form the image on the retina. By the convex glaſſes the rays are made to converge, and conſequently the image, which would otherwiſe have been behind the retina, is now formed in its proper place on the retina.

It is a long time, probably, before the child is able to uſe all the muſcles by which the pupil is contracted or expanded, ſo that the image ſhould

fall

fall exactly upon the retina, and then the ideas formed by the ſight muſt be exceedingly inaccurate. At firſt all objects will appear equally to touch the eye, and the apparent magnitude of the object will depend on the part of the retina covered by the image. By degrees theſe ideas are corrected, and the hands inſtruct, after ſome difficult experiments, the eye. The child diſcovers that objects are at a diſtance from its body, and that ſuch as make the ſame angle at the pupil are not always of the ſame real magnitude; hence it learns by degrees to combine together the angle under which an object is ſeen and the diſtance, and, according to its future employments in life, theſe ideas will be combined together with greater or leſs accuracy. The judgment of one perſon, accuſtomed to diſtant objects, will be very correct, while a perſon employed in the nicer works of art will be continually deceived in looking at the ſame diſtant objects, and the contrary.

An object will affect us differently, I have ſaid, according to the angle under which it is ſeen, and its diſtance. Firſt, if ſeveral objects are ſeen under the ſame angle, they would, to a perſon whoſe judgment was not better informed, appear to be of the ſame ſize, for they would make the ſame image upon the retina.

Again, if ſeveral objects were at the ſame diſtance from the eye, the magnitude of the viſual angles, and the ſmall images on the retinas, would depend on the magnitude of the objects.

Hence

Hence the real magnitude varies as the diſtance, when the viſual angle is the ſame; and it varies as the viſual angle, when the diſtance is the ſame; therefore the real magnitude of an object varies as the viſual angle, or apparent magnitude multiplied into the diſtance.

By repeated experiments the ſight of every perſon might be much improved. Suppoſe a yard to be placed at a certain diſtance from the eye, and the apparent magnitude of the yard and the diſtance to be ſo impreſſed on the ſpectator's mind, that on ſetting it up in any place he could walk back and fix exactly on the ſpot which ſhould be at the firſt given diſtance from his eye to the yard, he might, by degrees, accuſtom himſelf to meaſure objects ſo accurately, as to be very little liable to miſtakes in any of his calculations. What he could do by obſervation, we do by theory. Thus when the diſtance of an object and the angle under which it is ſeen are given, we can very nearly tell its real magnitude. Let QP (Fig. 40.) be the object, O the place of the ſpectator, at the diſtance of one hundred rods, and the angle under which it is ſeen thirty degrees. Then ſuppoſe R S to be a pole, exactly a rod high, erected perpendicularly at a rod's diſtance from O q, and note the angle under which it is ſeen. Then QP : R S : : QOP × OQ : : ROS × OR; let ROS $= a$, $\therefore$ QP : one rod : : $30° \times \overset{\text{rods}}{100} : a \therefore$ QP $= \dfrac{30 \times 100}{a}$

By the ſame proportion from the real and apparent

rent magnitudes we can find the diſtance, or from the real magnitude and the diſtance find the apparent magnitude.

For ſince QP : RS :: QOP × OQ : ROS × OR, QP : 1 :: QOP × OQ : *a* ∴ OQ $= \frac{a.\,QP}{QOP}$ and QOP $= \frac{a.\,QP}{OQ.}$

To ſee any object it has been obſerved (Fig. 39.) that an impreſſion muſt be made upon the retina; but to the eye, as to the other ſenſes, it happens, that an impreſſion does not always produce a ſenſation. There is an angle q M p of a determinate magnitude *, which varies indeed in the eyes of different perſons, but is ſuch that any object making a leſs angle in the pupil does not produce a ſenſation on the retina of ſuch a nature that a perſon can have a determinate idea of the object. This angle is in general about half a minute; and each perſon may diſcover the ſtrength of his ſight by taking an object of a determinate length,

* If the diſtance of any object from the eye is ſufficiently great for the rays to fall nearly parallel on the pupil, the ſame object is ſeen more enlarged and diſtinct the nearer it is brought to the eye, becauſe the image of any object on the retina will be greater or leſs in proportion to its apparent magnitude: when the object is too near the eye it continues to be enlarged, but is confuſed. The leaſt diſtance is about ſix inches.

The eye is capable of diſtinguiſhing objects that ſubtend an angle of half a minute of a degree, in which caſe the image on the retina is leſs in breadth than the $\frac{1}{7200}$ part of an inch, and the object, ſuppoſing it ſix inches diſtant, about the $\frac{1}{1100}$ part of an inch broad. And all ſmaller objects are inviſible to the naked eye.

and

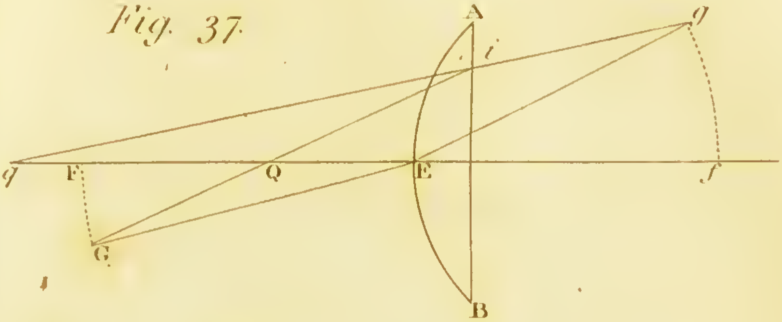


Fig. 37.

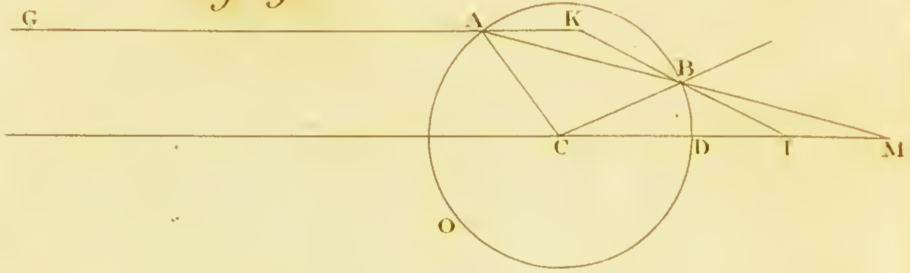


Fig. 38.

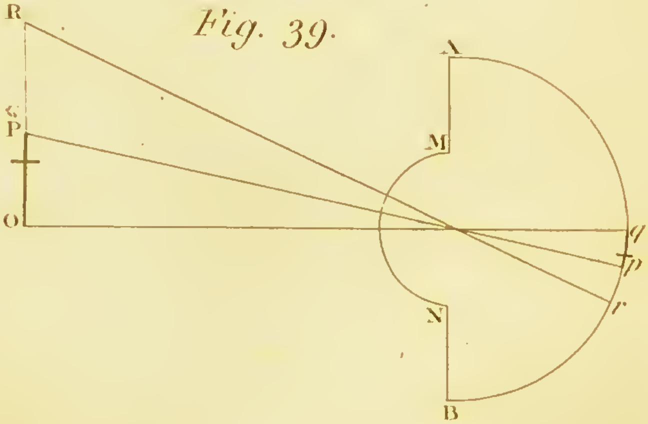


Fig. 39.

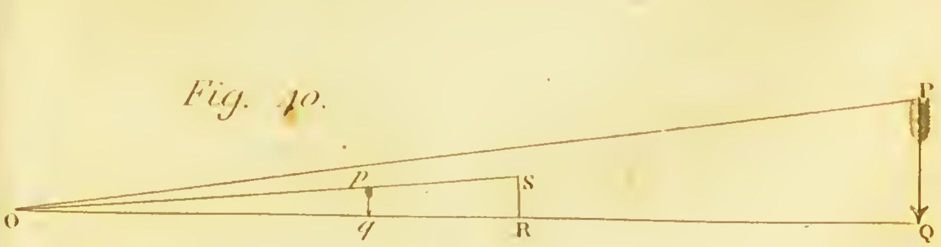


Fig. 40.

and removing it to ſuch a diſtance that it ſhall juſt ceaſe to be viſible, or appear only as a point. Let QP (Fig. 40.) be carried to that diſtance, then meaſure OQ, and ſay, as OQ : QP : : radius : tangent of QOP, and the angle QOP will be found, or the leaſt angle under which an object is ſeen.

When objects are beyond that diſtance, they conſequently are inviſible to us; and if by any art we can make them appear as if they were within this diſtance, they will then appear to us as other objects ſeen under the ſame angle, and at the ſame diſtance. Upon this principle depend many of the effects produced by glaſſes and teleſcopes, which I ſhall conſider firſt in the ſimpleſt caſes.

A perſon at O (Fig. 40.) can ſee diſtinctly, we will ſuppoſe, an object placed at the diſtance O*q*, but if it is removed beyond that diſtance his viſion is confuſed. Let an object be placed at the diſtance OQ, by means of a double concave glaſs, which makes the rays diverging from Q to appear to diverge from *q*, the object will be ſeen diſtinctly. On the other hand, if a perſon can ſee diſtinctly all objects at the diſtance QP, but none within that diſtance, by means of a double convex glaſs, which makes the rays diverging from *qp* to appear to diverge from QP, he will ſee the object *qp* diſtinctly. To find then by what ſort of lens an object is to be ſeen at any diſtance, we muſt take into conſideration the diſtance of the object, and the diſtance of diſtinct viſion, from which it will be eafy to find a lens of fuch a focal length as will make the object appear at the diftance required.

For in Plate XI. Fig. 41, 42, the triangles Q A q, E g q, are fimilar; therefore,

$$QA : Qq :: Eg : Eq, \text{ or}$$
$$QE : Qq :: Ef : Eq;$$
$$\therefore Ef = \frac{QE \times Eq}{Qq}$$

That is, the focal length of the glafs is equal to the rectangle under the diftances of diftinct vifion and the given object divided by the difference of thefe diftances.

If in the cafe of fhort-fighted perfons the object is at fuch a diftance that the rays coming from it to the eye may be confidered as parallel, Q E and Q q may be confidered as equal without any material error, and the focal length of the glafs will then be equal to the diftance of diftinct vifion.

By want of attention in the choice of glaffes, a defect in fight may be confiderably increafed, for the eye may be ftrained to an accommodation with the glafs. Short-fighted perfons, as they advance in years, are often found to improve in fight; long-fighted perfons, on the contrary, find their fight impaired by age. For the convexity in the pupil of both diminifhes with years *; in one cafe it was too great,

* This is the generally received opinion, but from fome obfervations lately communicated to the world in the Philofophical Tranfactions, by Dr. Hofack, there is reafon to believe, that the

great, and confequently the diminution was beneficial; in the other cafe it was already too fmall, and the diminution muft be confequently prejudicial.

With a fingle glafs the defects in fight, with refpect to many objects either too near or at too great a diftance, for the perfons labouring under them, are remedied; but it has been before obferved, that there is a certain angle to every perfon, which limits his fight, and confequently objects making an angle lefs than that to his eye muft be indiftinctly perceived. The art of man has difcovered a remedy, in a great degree, to this imperfection, and by means of a combination of glaffes has opened a wide field for his refearches into the wonders of nature; he can now trace the limbs of an infect invifible to the naked eye, or he can make the celeftial objects appear to him as if their diftance had been on a fudden diminifhed by many millions of miles.

the convexity and concavity are not changed, as was generally imagined, but that the mufcles of the eye grow weaker, like other mufcles, by age, and confequently are not able, as in early life, to vary the diftance between the retina and anterior furface of the eye, fo as to make it correfpond to the diftance of the object. This queftion will doubtlefs occupy the attention of the anatomift and philofopher.

Chap. VII.

VISION THROUGH TELESCOPES AND MICROSCOPES.

Principles on which these Instruments are constructed.—Defects.—Telescope of Galileo.—Microscope.—Reflecting Telescope.—Camera Obscura.—Magic Lanthorn.

LET QP (Plate XI. Fig. 43.) represent a very distant object, and let the rays coming from it, before they fall upon the eye, be intercepted by two convex lenses, placed at a distance from each other equal to the sum of the focal lengths. The lens A B is called the object-glass, from its being opposed to the object; C D the eye-glass, from its being nearest to the eye. Since the object is at a very great distance, the image made by refraction, *q p*, will be made at a distance from the object-glass equal to its focal length, and consequently the image is distant from the other glass exactly its focal length, and the rays diverging from any point of the image will, after refraction by the eye-glass, move parallel to the line drawn from that point through the center of the glass. The progress of the rays then, by which the object is seen, is easily traced. A ray P *b* will be refracted by the object-glass in the direction P A *p* D, and by the eye-glass in the direction d O parallel to p E. The angle, therefore, under which the image is seen, is equal to q E p, and the angle by which the object would have been seen by the naked eye is equal to q F p; consequently the magnitude of the object seen by the naked eye is to its magnitude, seen through the glasses, as q F p to q E p, that is, as q E : q F, or as the focal length of the eye-glass to the focal length of the object-glass.

By this simple combination of glasses an object appears inverted; but this is of no consequence to astronomers, and for objects on land several contrivances are used to rectify this appearance.

The quantity of the object visible depends upon the magnitude of the eye-glass. Let A p represent an extreme ray refracted by the object-glass; if the eye-glass is of such a magnitude as to intercept it, the whole of the object will be seen; if the eye-glass is too small for this purpose, join D A, C B, the extremities of the lenses, and the part of the image cut off by these lines will shew the proportional part of the object which is invisible.

Since the focal lengths of two lenses are susceptible of any proportion whatever, it might seem that nothing more was necessary than to take two lenses of determinate focal lengths to make us intimately acquainted with the most distant of the heavenly bodies; but after a certain length the difficulty of managing these glasses becomes insurmountable; and for distant objects on the earth, when the magnifying power is more than a hundred, the vapours on the earth would render viſion obſcure.

The breadth of the object-glaſs is of no conſequence as to the magnifying power, for whatever it may be, the image will be equally formed at the diſtance of its focal length; but the brilliancy of the image will be increaſed by the breadth, as a greater number of rays will then diverge from every given point of the image.

To make the image appear erect, two other convex lenſes are required, of equal focal lengths. The rays emerging from the eye-glaſs are intercepted by the firſt of theſe lenſes, and are made to converge to points at the diſtance of its focal length; thence they diverge, and being intercepted by the other lens at the diſtance of its focal length, they are made to proceed parallel to the lines drawn from each point through the center of the lens. Thus the firſt image of Q P (Fig. 44.) is *q p*, the ſecond K I. The apparent magnitude of the object is not changed by theſe glaſſes, and depends, as before, on the focal lengths of the object-glaſs and lens neareſt to it. The brilliancy of the object, however, will be diminiſhed, ſince ſeveral rays will be loſt in their paſſage through the two additional glaſſes.

An inſtrument made with glaſſes combined together in this manner, and inſerted in a tube, is called a refracting teleſcope; the latter word implying, according to its ſignification in the Greek language, the property of ſeeing objects at a diſtance. In placing

Fig. 41.

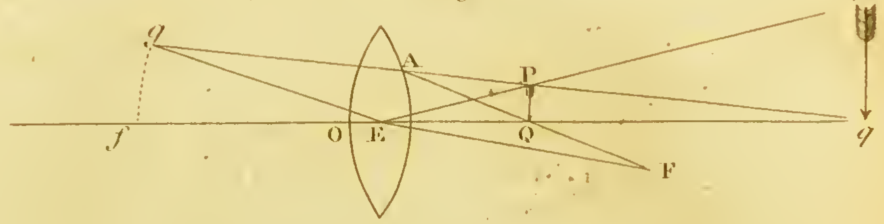


Fig. 42.

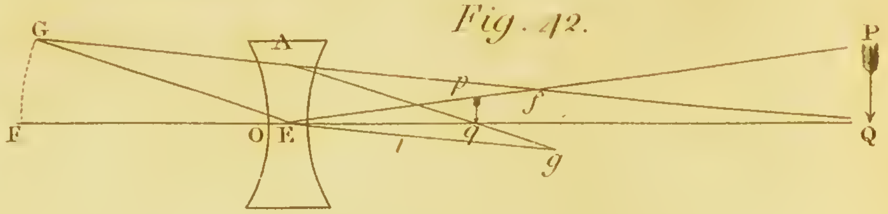


Fig. 43.

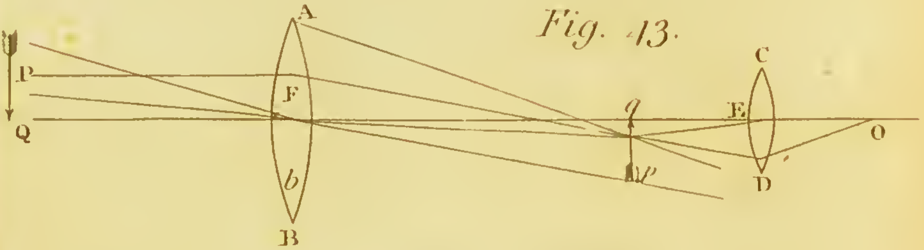


Fig. 44.

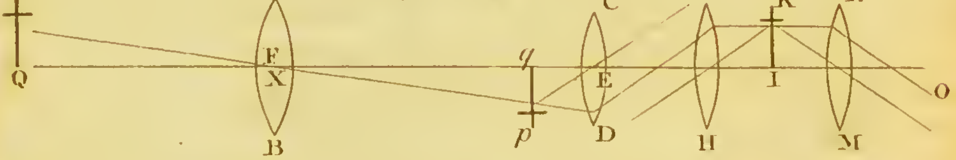
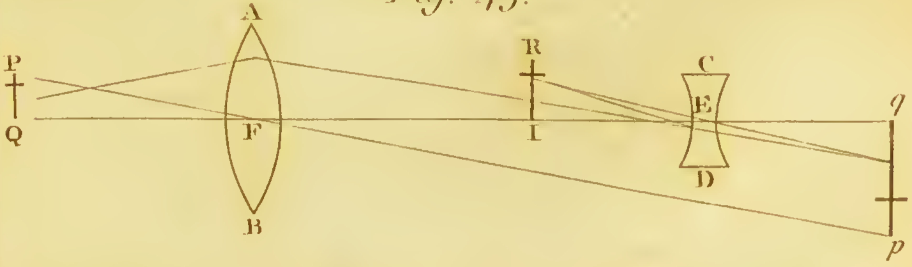


Fig. 45.



placing the glaſſes in this tube, care muſt be taken that the axes of the lenſes coincide, or, as it is evident from our principles, indiſtinct viſion only will be produced.

Inſtead of the two additional glaſſes, Galileo changed the convex eye-glaſs into a concave one, by which, as to the magnifying power, the ſame effect was produced. Thus (Fig. 45.) *qp* being the image of QP, by placing a double concave lens between this image and the object-glaſs, the rays converging to *p* appeared to diverge from R, and I R, the image ſeen by the eye at O, was made erect. In this caſe, the nearer the eye is placed to the glaſs, and the greater the pupil, the more of the object will be ſeen.

A microſcope, or an inſtrument formed to inſpect minute objects, is conſtructed exactly on the ſame principles. A globe of glaſs, or double convex lens, will, from what has been ſaid, anſwer the purpoſe; or, a minute object, ſeen through two convex lenſes, will be magnified in the proportion of the focal length of the object-glaſs to that of the eye-glaſs *. In all caſes, in whatever manner we combine

* Microſcopes are conſtructed in two different modes. The one is, by the interpoſition of a convex lens between the object and the eye, to render it diſtinct at a leſs diſtance than ſix inches, by which means its apparent magnitude increaſes as the diſtance is diminiſhed; and the other is, by placing the object ſo with reſpect to a convex lens, that its focal image may be much greater than itſelf, and contemplating that image inſtead of the object. The firſt are called ſimple or

bine our glaſſes to diſcover the magnifying power, it is neceſſary only to compare together the angles under which the object is ſeen through the eye-glaſs,

ſingle microſcopes, and the latter compound or double. The former is conſtructed in this manner: ſuppoſe a ſmall object ſituate very near the eye, ſo that the angle of its apparent magnitude may be large; then its image on the retina will alſo be large; but becauſe the pencils of rays are too divergent to be collected into their foci on the retina, it will be very confuſed and indiſtinct. Then let a convex lens be interpoſed, ſo that the diſtance between it and the object may be equal to the focal length at which parallel rays would unite, and the rays which diverge from the object, and paſs through the lens, will afterwards proceed, and conſequently enter the eye, parallel; they will therefore unite, and form a diſtinct image on the retina, and the object will be clearly ſeen, though if removed to the diſtance of ſix inches, its ſmallneſs would render it inviſible. The moſt convex lenſes, having the ſhorteſt focal diſtance of parallel rays, muſt magnify the moſt; for they permit the object to approach nearer the eye than thoſe do which are flatter.

A drop of water is a kind of microſcope, from its convex ſurface; for, if a ſmall hole is made in a plate of metal, or other thin ſubſtance, and carefully filled with a drop of water, ſmall objects may be ſeen through it very diſtinct, and much magnified.

In the compound microſcope, the image is contemplated inſtead of the object; it is of two kinds, the ſolar and the common double microſcope; in the latter, the *image* is viewed through a ſingle lens in the ſame manner as the *object* in a ſingle microſcope. The ſolar microſcope is conſtructed by placing a convex lens oppoſite a hole in a darkened chamber, and placing the object at a proper diſtance from the lens, the pencil of light will converge to a focus on a ſcreen, and the pencil which proceeds from the other point will converge to another focus, and the glafs, and that under which it would have been feen by the naked eye.

Inftead of lenfes only, for reafons hereafter to be mentioned, a combination has been formed of reflecting furfaces and lenfes, and from the names of the inventors, thofe of the greateft ufe are now called the Newtonian, Gregorian *, and Herfchelian telefcopes. The reflecting telefcope on the Gregorian principle, which is the moft common, as it is found to be the moft convenient, is conftructed in the following manner.

At the bottom of the great tube (Plate XII. Fig. 46.) T T T T is placed a large concave mirror D U V F, whofe principal focus is at *m*, and in the middle of this mirror is a round hole P, oppofite to which is placed the fmall mirror L, concave toward the great one, and fo fixed to a ftrong wire M, that it may be removed further from the great mirror, or nearer to it, by means of a long fcrew on the infide of the tube, keeping its axis ftill in the fame line

the intermediate points of the object will be formed into a picture, which will be as much larger than the object in proportion as the diftance of the fcreen exceeds that of the image from the lens.

* The difference between the Newtonian and Gregorian telefcope is, that in the former the fpectator looks in at the fide through an aperture upon a plane mirror, by which the rays reflected from the concave mirror are reflected to the eye-glafs, whereas in the latter, the reader will fee that he looks through the common eye glafs, which is in general more convenient, and therefore that is the telefcope which is now in the moft univerfal repute.

P *m n* with that of the great one. Now, ſince in viewing a very remote object, we can ſcarcely ſee a point of it, but what is, at leaſt, as broad as the great mirror, we may conſider the rays of each pencil, which flow from every point of the object, to be parallel to each other, and to cover the whole reflecting ſurface D U V F. But to avoid confuſion in the figure, we ſhall only draw two rays of a pencil flowing from each extremity of the object into the great tube, and trace their progreſs through all their reflections and refractions to the eye *f* at the end of the ſmall tube *t t*, which is joined to the great one.

Let us then ſuppoſe the object A B to be at ſuch a diſtance, that the rays C may flow from its lower extremity B, and the rays E from its upper extremity A; then the rays C falling parallel upon the great mirror at D, will be thence reflected converging in the direction D G, and by croſſing at I in the principal focus of the mirror, they will form the upper extremity I of the inverted image I K, ſimilar to the lower extremity B of the object A B, and paſſing on to the concave mirror L (whoſe focus is at *n*) they will fall upon it at *g*, and be thence reflected, converging in the direction *g* N, becauſe *g m* is longer than *g n*, and paſſing through the hole P in the large mirror, they would meet ſomewhere about *r*, and from the lower extremity *b* of the erect image *a b*, ſimilar to the lower extremity B of the object A B. But by paſſing through the plano-convex glaſs R in their way, they form that extremity of of the image at *b*. In the ſame manner the rays E, which come from the top of the object A B, and fall parallel upon the great mirror at F, are thence reflected, converging to its focus, where they form the lower extremity K of the inverted image I K ſimilar to the upper extremity A of the object A B, and thence paſſing on to the ſmall mirror L, and falling upon it at *h*, they are thence reflected in the converging ſtate *h* O; and going on through the hole P of the great mirror, they would meet ſomewhere about *q*, and form there the upper extremity *a* of the erect image *a b*, ſimilar to the upper extremity A of the object A B; but by paſſing through the convex glaſs R in their way, they meet and croſs ſooner, as at *a*, where that point of the erect image is formed. The like being underſtood of all thoſe rays which flow from the intermediate points of the object between A and B, and enter the tube T T, all the intermediate points of the image between *a* and *b* will be formed; and the rays paſſing on from the image through the eye-glaſs S, and through a ſmall hole *e* in the end of the leſſer tube *t t*, they enter the eye *f*, which ſees the image *a b* (by means of the eye-glaſs) under the large angle *c e d*, and magnified in length under that angle from *c* to *d*.

In the beſt reflecting teleſcopes, the focus of the ſmall mirror is never coincident with the focus *m* of the great one, where the firſt image I K is formed, but a little beyond it (with reſpect to the eye) as at *n*; the conſequence of which is, that the rays of the pencils will not be parallel after reflection from

from the small mirror, but converge so as to meet in points about *q*, *e*, *r*, where they would form a larger upright image than *a b*, if the glass R was not in their way, and this image might be viewed by means of a single eye-glass properly placed between the image and the eye; but then the field of view would be less, and consequently not so pleasant; for that reason the glass R is still retained to enlarge the scope or area of the field.

To find the magnifying power of this telescope, multiply the focal distance of the great mirror by the distance of the small mirror from the image next the eye, and multiply the focal distance of the small mirror by the focal distance of the eye-glass; then divide the product of the former multiplication by that of the latter, and the quotient will express the magnifying power *.

The immensely powerful telescopes of Dr. Herschel are on a different construction. This assiduous astronomer has made several speculums, which are so perfect as to bear a magnifying power of more than six thousand times in diameter on a distant object †. The object is reflected by a mirror as in the Gregorian telescope, and the rays are intercepted by a lens at a proper distance, so that the observer has his back to the object, and looks through the lens at the mirror. The magnifying power will

* Ferguson's Lectures, p. 235.

† See Phil. Transf. 1784.

in this caſe be the ſame as in the Newtonian teleſcope, but there not being a ſecond reflector, the brightneſs of the object viewed in the Herſchelian is greater than that in the Newtonian teleſcope.

There are ſeveral amuſing optical deceptions, which are effected by a proper combination of plane or convex glaſſes. My limits will not admit of my noticing more than two of the amuſing kind, namely, the magic lanthorn and the camera obſcura. The former is a microſcope upon the ſame principles as the ſolar microſcope, and may be uſed with good effect for magnifying ſmall tranſparent objects; but in general it is applied to the purpoſe of amuſement, by caſting the ſpecies or image of a ſmall tranſparent painting on glaſs upon a white wall or ſcreen, at a focal diſtance from the inſtrument.

Let a candle or lamp C (Fig. 47.) be placed in the inſide of a box, ſo that the light may paſs through the plano-convex lens N N, and ſtrongly illuminate the object O B, which is a tranſparent painting on glaſs, inverted and moveable before N N, by means of a ſliding piece in which the glaſs is ſet or fixed. This illumination is ſtill more increaſed by the reflection of light from a concave mirror S S, placed at the other end of the box, that cauſes the light to fall upon the lens N N, as repreſented in the figure. Laſtly a lens L L, fixed in a ſliding tube, is brought to the requiſite diſtance from the object O B, and a large erect image I M is formed upon the oppoſite wall.

The

The camera obſcura has the ſame relation to the teleſcope, as the ſolar microſcope has to the common double microſcope, and is thus conſtructed:

Let C D (Fig. 48.) repreſent a darkened chamber perforated at L, where a convex lens is fixed, the curvity of which is ſuch, that the focus of parallel rays falls upon the oppoſite wall. Then if A B be an object at ſuch a diſtance, that the rays which proceed from any given point of its ſurface to the lens L may be eſteemed parallel, an inverted picture will be formed on the oppoſite wall; for the pencil which proceeds from A will converge to *a*, and the pencil which proceeds from B will converge to *b*, and the intermediate points of the object will be depicted between *a* and *b**.

* Nicholſon's Natural Philoſ. vol. i. p. 347.

CHAP.

Chap. VIII.

OF THE DIFFERENT REFRANGIBILITY OF THE RAYS OF LIGHT, AND OF COLOURS *.

Errors and Inconveniencies in optical Inſtruments from the Refraction of Light.—Newton, while attempting to remedy theſe, diſcovers a new Property in Light.—Phenomena and Cauſe of Colours.—Achromatic Teleſcope.—The Eye an achromatic optical Inſtrument.—Experiments on Colours.—Cauſe of the permanent Colour of opake Bodies.

IN the preceding chapters we have ſeen, that in finding the foci, ſome errors naturally ariſe by refraction from every ſurface whatever, and by reflexion from all ſpherical ſurfaces. When parallel rays are refracted by a lens (as in Plate XII. Fig. 49.) the farther the ray is from its center, the greater will be its deviation from the point F which we called the focus. This deviation M F is called the longitudinal aberration, and F N its latitudinal aberration; and as we ſee on a piece of paper a ſmall circle formed by the rays of the ſun

* This ſubject has been partly anticipated in the 1ſt and 2d chapters of this book, in which it was neceſſary to give a ſuperficial account of the diſcoveries concerning light, and of its general properties. The reader will, however, have no cauſe to regret a little repetition, as the ſubject is not very clear to a learner, and cannot be too forcibly impreſſed on the mind.

intercepted

intercepted by a convex lens, its magnitude depends on its radius, or the latitudinal aberration F N. This aberration depends on the aperture of the glaſs A B, and it does not increaſe in the ſimple proportion, but the triplicate of the ſemi-aperture*. Thus, if P V and p V repreſent the ſame glaſs

* Let K a, L b, (Plate XII. Fig. 59.) be two parallel rays very near to each other, incident on the concave refracting ſurface A C B at a, b, it is required to find m, the interſection of the rays after refraction. Draw E I, E H the ſines of incidence and refraction; and from the point H draw H G perpendicular to the radius E b, and from G draw G m parallel to the incident rays, and cutting the refracted ray bf in m, m is the point required.

For $AaE = amc + acm = amc + cEb + cbE$ $\therefore$ $AaE - cbE = amc + cEb =$ Increment of the angle of refraction, and $cEb =$ increment of the angle of incidence $\therefore$ increment of the angle of incidence : increment of refraction : : $aEb : aEb + amb$.

$\therefore$ $aEb : amb$: : increment of incidence : increment of refraction — increment of incidence.

But when the ſines of angles are to each other in a given ratio, the increments of the angles vary as their tangents.

$aEb : amb$: : tangent of incidence : tangent of refraction — tangent of incidence.

But H G is the tangent of refraction, H b G and O G is the tangent of incidence O b G.

$\therefore$ $aEb : amb$: : O G : H O.

With m as center, and mb radius, deſcribe the arc bd, then

$$aEb : amb :: \frac{ab}{Eb} : \frac{bd}{bm}.$$

Now $ab : bd$: : Eb : bH.

Hence bM : bH : : O G : H O, and G m joining the points G and m is parallel to the incident rays, and conſequently by drawing

Fig. 46.

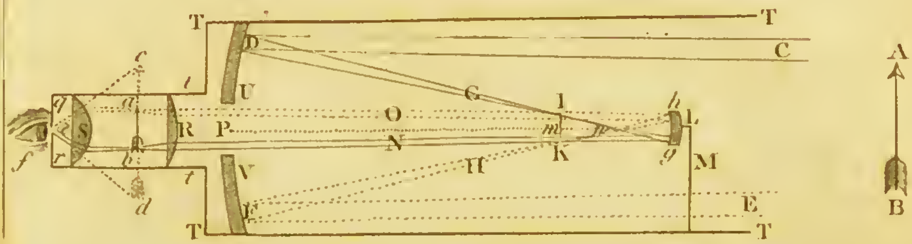


Fig. 47. Magic Lanthorn.

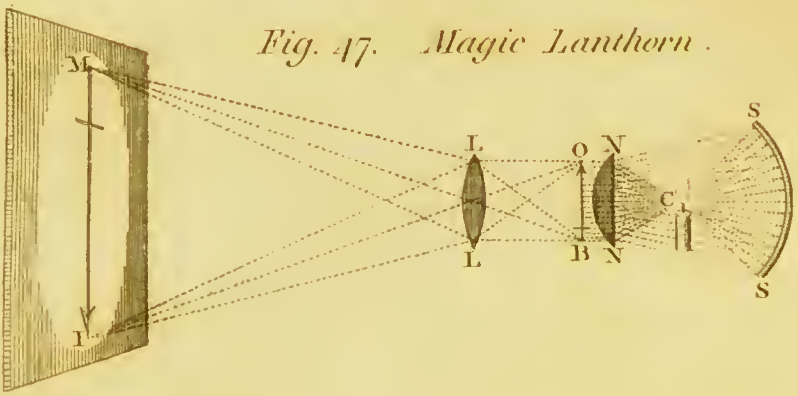


Fig. 48. Camera Obscura.

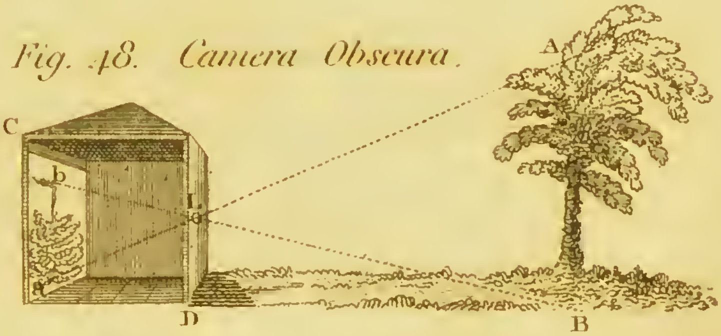
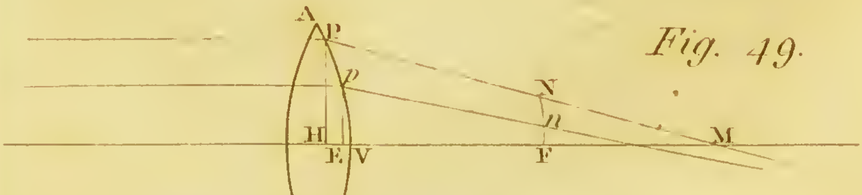


Fig. 49.



glaſs with different apertures P H, p E, the latitudinal aberration N F in the firſt caſe will be to that of n F in the ſecond as the cube of P H to the cube of p E.

Philoſophers,

drawing from G a parallel to the incident rays, the point of interſection of the refracted rays is determined.

Hence, ſince $bH = bE \times$ coſ. of E b H, the radius being unity, the diſtance of the interſection from the point of incidence is found, by making as the difference of the tangents of incidence and refraction to the tangent of incidence ſo is radius of the ſurface multiplied into the coſ. of refraction, to the diſtance of the point of interſection from the point of incidence.

The diſtance m of the interſection mg from the axis C F, varies as the cube of the ſemi-aperture of the ſpherical ſurface.

For $mg = DG = EG \times \text{Sin. } GED = EG \times \text{S. } EbI$

$EG = HE \times \text{Cos. } HEG = HE \times \text{S. } HbE.$

$HE = Eb \times \text{S. } HbE.$

$\therefore mg = Eb \times \overline{\text{S. } HbE}|^2 \times \text{S. } EbI.$

but S. H b E varies, as S. E b I and E b is a conſtant quantity.

$\therefore mg$ varies as $\overline{\text{S. } EbI}|^3$, that is as $\overline{EI}|^3$, that is as $\overline{\text{Semi-aperture}}|^3$.

If the line mg be now ſuppoſed to move parallel to itſelf on the axis C F, and to be made proportional in every place to the cube of the ſemi-aperture, a curve will be formed to which the refracted rays will be tangents, and as the adjacent rays croſs each other in the points m, or the extremities of the ordinate; the light in theſe points will be ſtronger than within its area; and the curve thus formed which experiment ſhews to us, in various inſtances, is called a cauſtick.

All the rays incident on the ſurface b C will paſs within the ſpace mg, and conſequently if the rays of the ſun are refracted by a concave ſurface, and received by an opaque body perpendicular to the axis at the diſtance C g, a circle of light will be formed, Philosophers, considering the errors to which they were thus exposed by the spherical form of their glasses, employed their thoughts a long time on various modes to bring the rays of light more accurately to a focus. The greatest of philosophers, Newton himself, was endeavouring to make a reflector of a parabolical form, which, if he had succeeded in his attempt, would manifestly have obviated this inconvenience, when his thoughts were turned into another channel by a discovery, which taught him that the errors arising from the spherical form of his glasses were trifling, compared with what must arise from his newly discovered property of the rays of light. Each ray, notwithstanding the exceeding minuteness of its breadth, was now found to be compounded of seven other rays, from

formed, whose density is greater at the circumference and least at its center. But though all the refracted rays will pass through the area of a circle at the distance C*g*, whose diameter is *mi*, they will, at a greater distance from the surface, pass through a much smaller circle *np*, which, when it is the least, is called the circle of least diffusion, and in this circle the density of rays, and consequently the heat, is the greatest. In this circle the density of the rays will be the greatest in the center, and it decreases between the center and the circumference to a place where it is a minimum, and consequently increases again to the circumference. The investigation of this property would carry us too far into the abstruse mathematics; but what has been said sufficiently shews the nature of the diffusion of the rays of light from the figure of the surface, which is now known to occasion a much greater error, in proportion to that arising from refrangibility, than was supposed by our first philosopher.

whose

whofe various combinations all the beautiful colours in nature originate.

The experiment on which this difcovery is founded is thus defcribed by Newton himfelf.

'In a very dark chamber, at a round hole F (Plate XIII. Fig. 50.) about one-third of an inch broad, made in the fhut of a window, I placed a glafs prifm A B C, whereby the beam of the fun's light, S F, which came in at that hole, might be refracted upwards, toward the oppofite wall of the chamber, and there form a coloured image of the fun, reprefented at P T. The axis of the prifm (that is, the line paffing through the middle of the prifm, from one end of it to the other end, parallel to the edge of the refracting angle) was in this and the following experiments perpendicular to the incident rays. About this axis I turned the prifm flowly, and faw the refracted light on the wall, or coloured image of the fun, firft to defcend, and then to afcend. Between the defcent and afcent, when the image feemed ftationary, I ftopped the prifm and fixed it in that pofture.

'Then I let the refracted light fall perpendicularly upon a fheet of white paper, M N, placed at the oppofite wall of the chamber, and obferved the figure and dimenfions of the folar image, P T, formed on the paper by that light. This image was oblong, and not oval, but terminated by two rectilinear and parallel fides and two femicircular ends. On its fides it was bounded pretty diftinctly; but on its ends very confufedly and indiftinctly, the light there decaying and vanishing by degrees. At the distance of 18½ feet from the prism, the breadth of the image was about 2⅛ inches, but its length was about 10¼ inches, and the length of its rectilinear sides about eight inches; and A C B, the refracting angle of the prism, whereby so great a length was made, was 64 degrees. With a less angle the length of the image was less, the breadth remaining the same. It is farther to be observed, that the rays went on in strait lines from the prism to the image, and therefore at their going out of the prism, had all that inclination to one another from which the length of the image proceeded. This image P T was coloured, and the more eminent colours lay in this order from the bottom at T to the top at P; red, orange, yellow, green, blue, indigo, violet, together with all their intermediate degrees, in a continual succession, perpetually varying.'

Our philosopher continued his experiments, and by making the rays thus decompounded pass through a second prism, he found that they did not admit of farther decomposition, and that objects placed in the rays producing one colour always appeared to be of that colour. He then examined the ratio between the sines of incidence and refraction of these decompounded rays, and found that each of the seven primary colour-making rays, as they may be called, had certain limits within which they were confined. Thus, let the sine of incidence in glass be divided into fifty equal parts, the sine of refraction

refraction into air of the leaſt and moſt refrangible rays will contain reſpectively 77 and 78 ſuch parts. The ſines of refraction of all the degrees of red will have the intermediate degrees of magnitude, from 77 to $77\frac{1}{8}$, orange from $77\frac{1}{8}$ to $77\frac{1}{5}$, yellow from $77\frac{1}{5}$ to $77\frac{1}{3}$, green from $77\frac{1}{3}$ to $77\frac{1}{2}$, blue from $77\frac{1}{2}$ to $77\frac{2}{3}$, indigo from $77\frac{2}{3}$ to $77\frac{7}{9}$, and violet from $77\frac{7}{9}$ to 78.

According to the properties of bodies in reflecting or abſorbing theſe rays, the colours which we ſee in them are formed. If every ray falling upon an object was reflected to our eyes, it would appear white; if every ray was abſorbed it would appear black; between theſe two appearances innumerable ſpecies of colours may be formed by reflection or tranſmiſſion of the various combinations of the colour making rays *. If the rays alſo of light were

* The original or component rays of light are ſeparable from each other, not only by refraction, or by varying the angle of incidence on a reflecting ſurface, but are likewiſe at like incidences more or leſs reflectible, according to the thickneſs or diſtance between the two ſurfaces of the medium on which they fall. They are alſo liable to be turned out of their direct courſe by approaching within a certain diſtance from a body, by which means a ſeparation enſues, the rays being more or leſs deflected as they differ in colour. Of theſe circumſtances it will be proper to give ſome account.

If a convex glaſs or lens, or a portion of a ſphere, is laid upon another plane glaſs, it is evident that it will reſt or touch at one particular point only; and, therefore, that at all other places between the adjacent ſurfaces will be interpoſed a thin plate of air, the thickneſs of which will increaſe in a certain

R 2 ratio,

were not thus compounded, every object would appear of the ſame colour, and an irkſome uniformity would prevail over the face of nature.

We have ſeen that when rays of light were refracted by any ſurface, the focus after refraction depended on the ratio between the ſines of incidence and refraction, and that this focus was not a mathematical point. The reader will naturally infer, that the aberration muſt be conſiderably increaſed, when for each order of colour-making rays a different ratio between theſe ſines muſt be aſſumed. Common obſervers, without underſtanding the cauſe, may be made ſenſible of this by noticing

ratio, according to the diſtance from the point of contact. Light incident upon ſuch a plate of air is diſpoſed to be tranſmitted or reflected according to its thickneſs; thus, at the center of contact, the light is tranſmitted, and a black circular ſpot appears; this ſpot is environed by a circle, the colours of which, reckoning from the internal part, are blue, white, yellow, red; then follows another circular ſeries, viz. violet, blue, green, yellow, red; then purple, blue, green, yellow, red; green, red; greeniſh blue, red; greeniſh blue, pale red; greeniſh blue, reddiſh white.

Theſe are the colours which appear by reflection. By the tranſmitted light the following ſeries are ſeen. At the center, white, then yellowiſh red, black, violet, blue, white, yellow, red, &c.; ſo that the tranſmitted light at any thickneſs, inſtead of white, appears of the compounded colour which it ought to have after the ſubtraction of ſome of the conſtituent colours by reflection; after which ſeries, the colours become too faint and diluted to be diſcerned. It is curious to obſerve, that the glaſſes will not come into contact without a conſiderable degree of preſſure. *Nicholſon's Philoſophy,* vol. i. p. 282.

the

the colours of objects ſeen through a teleſcope; and from the difficulty of the ſubject it might ſeem impoſſible that any remedy ſhould be applied to the inconvenience. Yet who ſhall ſet bounds to the ſagacity of man? Mathematicians could point out certain combinations of forms and refrangible powers by which the rays might come colourleſs, as the white making rays are commonly called, to the eye; and a celebrated optician of our own times, Mr. Dollond, has had the merit of realizing, in great meaſure, their theories. By making a compound lens of three different ſubſtances of different refrangible powers, the rays of light, which were diſperſed too much by one convex lens, are brought nearer to an union with each other, and the teleſcopes made with an object glaſs of this kind are now commonly uſed, and well known by the name of achromatic teleſcopes; the word achromatic being uſed by that pedantry which infects moſt of our philoſophers, who love to give a Greek word, unintelligible to the greater part of their readers, inſtead of the equally ſignificant term in our own language, colourleſs.

'The object-glaſſes of Mr. Dollond's teleſcopes are compoſed of three diſtinct lenſes, two convex and one concave; of which the concave one is placed in the middle, as is repreſented in Fig. 51. where *a* and *c* ſhow the two convex lenſes, and *b b* the concave one, which is by the Britiſh artiſts placed in the middle. The two convex ones are made of London crown glaſs, and the middle one of white flint glaſs; and they are all ground to ſpheres of different radii, according to the refractive powers of the different kinds of glaſs, and the intended focal diſtance of the object-glaſs of the teleſcope. According to Boſcovich, the focal diſtance of the parallel rays for the concave lens is one-half, and for the convex glaſs one-third of the combined focus. When put together, they refract the rays in the following manner. Let *a b*, *a b* (Fig. 52.) be two red rays of the ſun's light falling parallel on the firſt convex lens *c*. Suppoſing there was no other lens preſent but that one, they would then be converged into the lines *b e*, *b e*, and at laſt meet in the focus *q*. Let the lines *g h*, *g h*, repreſent two violet rays falling on the ſurface of the lens. Theſe are alſo refracted, and will meet in a focus; but as they have a greater degree of refrangibility than the red rays, they muſt of conſequence converge more by the ſame power of refraction in the glaſs, and meet ſooner in a focus, ſuppoſe at *r*.—Let now the concave lens *d d* be placed in ſuch a manner as to intercept all the rays before they come to their focus. If this lens was made of the ſame materials, and ground to the ſame radius with the convex one, it would have the ſame power to cauſe the rays to diverge that the former had to make them converge. In this caſe, the red rays would become parallel, and move on in the line *o o*, *o o*: but the concave lens, being made of flint glaſs, and upon a ſhorter radius, has a greater refractive power, and therefore they diverge a little after they come out of it; and if no third lens was interpoſed, they would proceed di-

verging

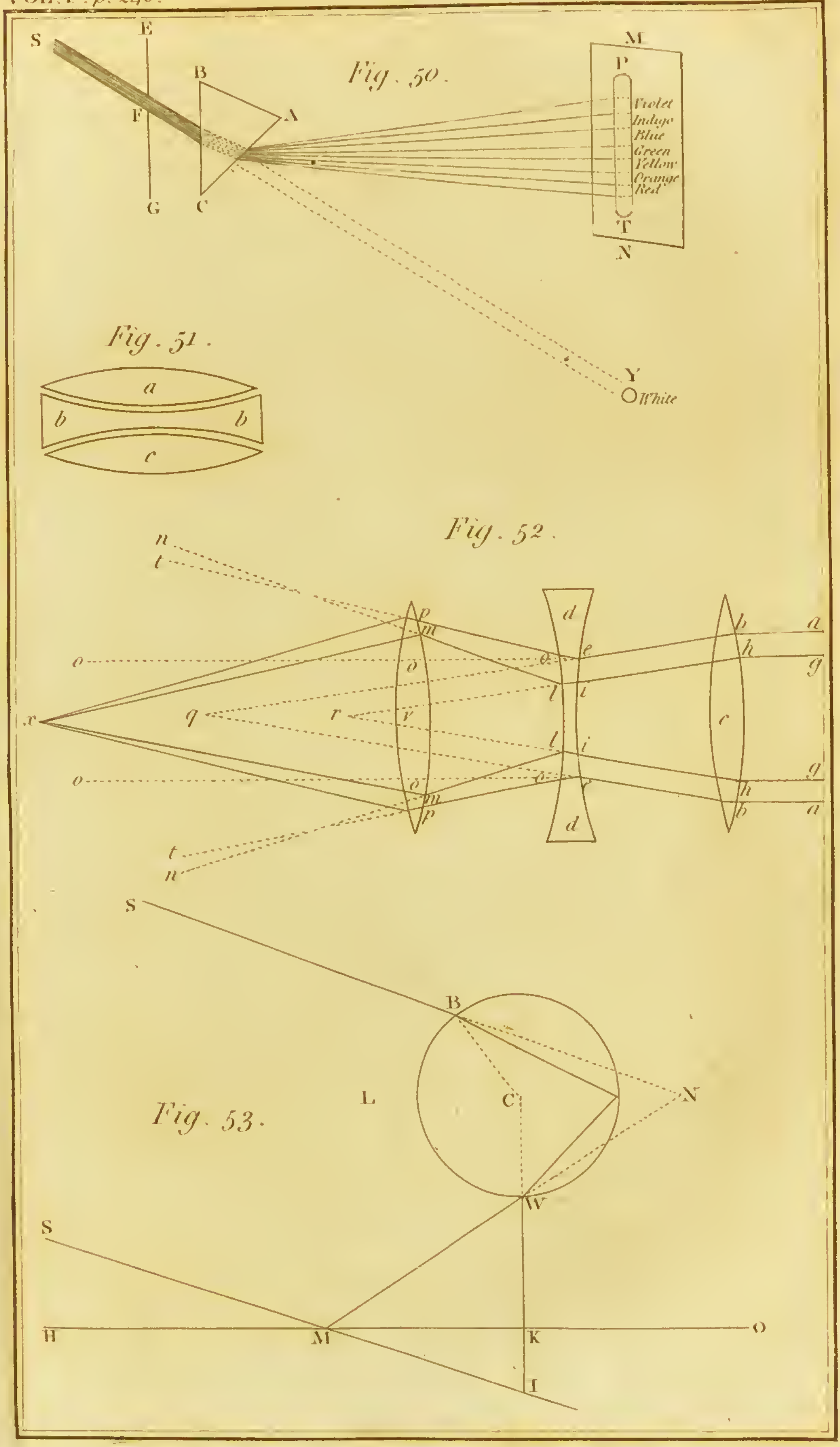


Fig. 50.
S
E
F
G
B
A
C
M
P
Violet
Indigo
Blue
Green
Yellow
Orange
Red
T
N
Y
White
Fig. 51.
a
b
b
c
Fig. 52.
Fig. 53.
S
B
C
L
N
W
S
H
M
K
O
I

verging in the lines *o p t, o p t*; but, by the interposition of the third lens *o v o*, they are again made to converge, and meet in a focus somewhat more distant than the former, as at *x*. By the concave lens the violent rays are also refracted, and made to diverge: but having a greater degree of refrangibility, the same power of refraction makes them diverge somewhat more than the red ones; and thus, if no third lens was interposed, they would proceed in such lines as *l m n, l m n*. Now as the differently coloured rays fall upon the third lens with different degrees of divergence, it is plain, that the same power of refraction in that lens will operate upon them in such a manner as to bring them all together to a focus very nearly at the same point. The red rays, it is true, require the greatest power of refraction to bring them to a focus; but they fall upon the lens with the least degree of divergence. The violet rays, though they require the least power of refraction, yet have the greatest degree of divergence; and thus all meet together at the point *x*, or very nearly so *.'

The more we investigate the works of nature, the greater reason have we to admire the wisdom of its author, and that wonderful adaptation of our organs, in the minutest particulars, to the general laws which pervade the universe. The subject before us affords a striking instance to corroborate this remark. We have hitherto supposed the eye to be a lens capable only of enlarging and contracting,

* Encyclop. Brit. vol. xiii. p. 354.

and conſequently, from the deſcription now given of the rays of light, it muſt be incapable of obviating the confuſion which muſt ariſe from their different degrees of refrangibility. But here the uſe of that wonderful ſtructure of parts, and the different fluids in the eye, is clearly ſeen. The eye is, in fact, a complex lens. Each fluid has its proper degree of refrangible power. The ſhape of the lenſes is altered at will, according to the diſtance of the object; and the three ſubſtances having the proper powers of refrangibility, the effects of an achromatick glaſs are without difficulty performed by the eye, whoſe mechanical ſtructure and judicious arrangement of ſubſtances it is in vain for the art of man to imitate.

From what has been ſtated, the principal phenomena of colours may, without much difficulty, be explained.

If all the different-coloured rays which the priſm affords are re-united by means of a concave mirror, the produce will be *white*; yet theſe ſame rays, which, taken together, form white, give, after the point of their re-union, that is, beyond the point where they croſs each other, the ſame colours as thoſe which departed from the priſm, but in a reverſed order, by the croſſing of the rays; the reaſon of which is clear; for the ray being white before it was divided by the priſm, muſt neceſſarily become ſo by the re-union of its parts, which the difference of refrangibility had ſeparated, and this re-union cannot in any manner tend to alter or deſtroy the nature

nature of the colours; it follows then that they muſt appear again beyond the point of croſſing.

In the ſame manner, if we mix a certain proportion of red colour with orange, yellow, green, blue, indigo, and violet, a colour will be produced which reſembles that which is made by mixing a little black with white, and which would be entirely white if ſome of the rays were not loſt or abſorbed by the groſſneſs of the colouring matter.

A colour nearly approaching to white is alſo formed by colouring a piece of round paſteboard with the different priſmatic colours, and cauſing it to be turned round ſo rapidly that no particular colour can be perceived.

If to a ſingle ray of the ſun divided by the priſm, which will then form an oblong-coloured ſpectrum, a thick glaſs deeply coloured with one of the primitive colours is applied, for example red, the light which paſſes through will appear red only, and will form a round image.

If two thick glaſſes, the one red and the other green, are placed one upon another, they will produce a perfect opacity, though each of them, taken ſeparately, is tranſparent, becauſe the one permits the red rays only to paſs through it, and the other only green ones, therefore when theſe two glaſſes are united, neither of thoſe kind of rays can reach the eye, becauſe the firſt permits only red rays to paſs, whereas the ſecond receives only green ones, which are the only rays it can tranſmit.

If the rays of the ſun are made to fall very obliquely

liquely upon the interior ſurface of a priſm, the violet-coloured rays will be reflected, and the red, &c. will be tranſmitted; if the obliquity of incidence is augmented, the blue will be alſo reflected, and the other tranſmitted; the reaſon of which is, that the rays which have the moſt refrangibility are alſo thoſe which are the eaſieſt reflected *.

In whatever manner we examine the colour of a ſingle priſmatic ray, we ſhall always find, that neither refraction, reflection, nor any other means, can make it forego its natural hue; but if we examine the artificial colouring of bodies by a microſcope, it will appear a rude heap of colours, unequally mixed. If we mix a blue and yellow to make a common green, it will appear moderately beautiful to the naked eye; but when we regard it with microſcopic attention, it ſeems a confuſed maſs of yellow and blue parts, each particle reflecting but one ſeparate colour.

To determine the cauſe of the permanent colours of opake bodies, a ſeries of experiments was inſtituted by Mr. Delaval, as noticed in the hiſtorical part of this book. He prepared a great variety of coloured fluids, which he put in phial bottles of a ſquare form. The backs of theſe phials he coated over with an opake ſubſtance, leaving the front of the phial uncovered, and the whole of the neck. On expoſing them to the incident light, he found, that from the parts of the phials which were covered at the back no light whatever was reflected, but it was

* Briſſon, Traité Elem. de Phyſique, tom. ii. page 361.

perfectly

perfectly black, while the light tranſmitted through the uncoated parts of the phials was of different colours. The ſame fluids, ſpread thinly on a white ground, exhibited their proper colours; the light indeed being in this caſe reflected from the white ground, and tranſmitted through a coloured medium. It is almoſt unneceſſary to add, that when ſpread upon a black ground they afforded no colour.

The ſame experiments were repeated with glaſs tinged of various colours, and the reſult was perfectly the ſame. When theſe glaſſes are of ſuch a thinneſs, and are tinged ſo dilutely that light is tranſmitted through them, they appear vividly coloured; when in larger maſſes, and the tinging matter more denſely diffuſed through them, they are black; when the tranſmitted light, in the tranſparent plates of theſe glaſſes, was intercepted by covering the further ſurface, they appeared black.

From theſe different phenomena Mr. Delaval clearly deduces theſe remarks—1ſt, That the colouring particles do not reflect any light. 2dly, That a medium, ſuch as Sir Iſaac Newton has deſcribed, is diffuſed over the anterior and further ſurfaces of the plates, whereby objects are reflected equally and regularly as in a mirror.

When a lighted candle is placed near one of theſe coloured plates, the flame is reflected by the medium diffuſed over the anterior ſurface; the image thus reflected reſembles the flame in ſize and colour, for it is ſcarcely ſenſibly diminiſhed, and is not at all tinged with colours: if the plate is not very maſſy,

maſſy, or too deeply tinged, there appears a ſecondary image of the flame, reflected from the further ſurface of the glaſs, and as the light, thus reflected, paſſes back through the coloured glaſs, it is vividly tinged.

The ſecondary image is leſs than that which is reflected from the anterior ſurface. This diminution is occaſioned by the loſs of that part of the light which is abſorbed in paſſing through the coloured glaſs.

The next object of this ingenious philoſopher was to obtain the colouring particles pure and unmixed with other media. To this end he reduced ſeveral tranſparent coloured liquors to a ſolid conſiſtence by evaporation, and in this ſtate the colouring particles reflected no light, but were entirely black.

To determine the principle on which opake bodies appear coloured, it is therefore only neceſſary, in the firſt place, to recollect, that all the coloured liquors appeared ſuch only by tranſmitted light; and 2dly, that theſe liquors, ſpread thinly upon a white ground, exhibited their reſpective colours; he therefore concludes, that all coloured bodies, which are not tranſparent, conſiſt of a ſub-ſtratum of ſome white ſubſtance, which is thinly covered with the colouring particles.

On extracting carefully the colouring matter from the leaves, wood, and other parts of vegetables, he found that the baſis was a ſubſtance perfectly white. He alſo extracted the colouring matter from diffe-

rent

rent animal ſubſtances; from fleſh, feathers, &c. whence the ſame concluſion was directly proved.

Fleſh conſiſts of fibrous veſſels, containing blood, and is perfectly white when diveſted of the blood by ablution; and the florid red colour of the fleſh proceeds from the light which is reflected from the white fibrous ſubſtance, through the red tranſparent covering formed by the blood.

The reſult was the ſame from an examination of the mineral kingdom.

Some portions of light are reflected from every ſurface of a body, or from every different medium into which it enters. Thus, tranſparent bodies reduced to powder appear white, which is no other than a copious reflection of the light from all the ſurfaces of the minute parts, and from the air which is interpoſed between theſe particles.

The general appearance of a ſtrong infuſion of cochineal is black; but when agitated, its ſurface is covered with a red froth. The reaſon is, that the light is reflected from the globules of air incloſed in each of the bubbles which conſtitute the froth, and is tranſmitted through the films of red liquor which cover them. Several vitreous ſubſtances in like manner appear black in a ſolid maſs, but when powdered, of a different colour. The action of theſe powders on the rays of light is the effect of the diſcontinuance of their parts, and the air being admitted into the interſtices, the light is tranſmitted through the thin tranſparent particles of the glaſs, which give it that tinge which the powder exhibits.

7 If

If oil, inftead of air, intercedes the interftices of powdered fubftances, in proportion as it approaches to the denfity of the fubftances themfelves, and as it exceeds air in this refpect, it renders the colour proportionably darker. "Thus when indigo, and other tranfparent paints, are united with oil, the air is expelled from their interftices, and the oil which is admitted in its ftead, from the nearnefs of its denfity to that of the powder, reflects no fenfible light, fo that the mafs, which confifts of fuch uniformly denfe media, is black." "When fmooth furfaces of dark-coloured marble or flate, or any other polifhed fubftance, are fcratched, the air enters into the interftices which are opened by this operation, and according to the excefs of its rarity over that of the maffes which it intercedes, it reflects a whiter or lighter-coloured hue. By polifhing the furface alfo, the air is removed from them, and the dark hue is reftored."

From thefe experiments he concludes, "that vegetable, animal, and mineral coloured matter is tranfparent; that it does not reflect colours, but only exhibits them by tranfmiffion; that opake coloured bodies confift of tranfparent matter covering opake white particles, and tranfmitting the light which is reflected from them."

With refpect to the femi pellucid fubftances, fuch as the folution of lignum nephriticum, &c. which appear of one colour by incident and another by tranfmitted light, he fays, "they confift of pellucid media, through which white or colourlefs opake

2 particles

particles are diffused. These white particles, he adds, are disposed at such distances from each other, that some of the incident rays of light are capable of passing through the intervals which intercede them, and thus are transmitted through the semi-pellucid mass. Some sorts of rays penetrate through the masses, whilst other sorts, which differ from them in refrangibility, are refracted by the white or colourless particles. Thus, when pellucid colourless glass is melted with arsenic, the arsenic is thereby divided into minute opake particles, which are equally diffused through the glass. If only a small quantity of arsenic is used in this compound, the white particles are thinly disseminated in it. When glass of this composition is held between the window and the eye, it exhibits a yellow or orange tinge; when viewed by incident light it is blue. The yellow or orange arises from the less refrangible rays, from the mixture of which that colour results. The more refrangible are reflected back by the white particles.

CHAP.

CHAP. IX.

OF THE RAINBOW, AND OTHER REMARKABLE PHENOMENA OF LIGHT.

Of the primary and ſecondary Rainbow.—Why the Phenomenon aſſumes the Form of an Arch.—At what Angles the different Colours are apparent.—Lunar Rainbow.—Marine Bow.—Coloured Bows ſeen on the Ground.—Halo or Corona.—Curious Phenomena ſeen on the Top of the Cordileras.—Similar Appearance in Scotland.—Parhelia, or Mock Suns.—Singular Lunar Phenomenon.—Blue Colour of the Atmoſphere.—Red Colour of the Morning and Evening Clouds.—Colour of the Sea.

SINCE the rays of light are found to be decompounded by refracting ſurfaces, we can no longer be ſurpriſed at the changes produced in any object by the intervention of another. The vivid colours, which gild the riſing or the ſetting ſun, muſt neceſſarily differ from thoſe, which adorn its noon day ſplendor. There muſt be the greateſt variety which the livelieſt fancy can imagine. The clouds will aſſume the moſt fantaſtic forms, or will lower with the darkeſt hues, according to the different rays which are reflected to our eyes, or the quantity abſorbed by the vapours in the air. The ignorant multitude will neceſſarily be alarmed by the ſights in the heavens, by the appearance at one time of three, at another of five ſuns, of circles

cles of various magnitudes round the ſun or moon, and thence conceive that ſome fatal change muſt take place in the phyſical or the moral world, ſome fall of empires or tremendous earthquakes, while the optician contemplates them merely as the natural and beautiful effects produced by clouds or vapour in various maſſes upon the rays of light.

One of the moſt beautiful and common of theſe appearances deſerves particular inveſtigation, as, when this ſubject is well underſtood, there will be little difficulty in accounting for others of a ſimilar nature, dependant on the different refrangibility of the rays of light. Frequently, when our backs are turned to the ſun, and there is a ſhower either around us or at ſome diſtance before us, a ſpecies of bow is ſeen in the air, adorned with the ſeven primary colours. The appearance of this bow, in poetical language called the iris, and in common language the rainbow, was an inexplicable myſtery to the antients; and, though now well underſtood, continues to be the ſubject of admiration to the peaſant and the philoſopher.

We are indebted to Sir Iſaac Newton for the explanation of this appearance, and by various eaſy experiments we may convince any man that his theory is founded on truth. If a glaſs globe is ſuſpended in the ſtrong light of the ſun, it will be found to reflect the different priſmatic colours exactly in proportion to the poſition in which it is placed; in other words, agreeably to the angle which it forms with the ſpectator's eye and the incidence of the rays of light. The fact is, that innumerable pencils of light fall upon the surface of the globe, and each of these is separated as by a prism. To make this matter still clearer, let us suppose the circle B O W (Plate XIV. Fig. 53.) to represent the globe, or a drop of rain, for each drop may be considered as a small globe of water. The red rays, it is well known, are least refrangible; they will therefore be refracted, agreeably to their angle of incidence, to a certain point O in the most distant part of the globe; the yellow, the green, the blue, and the purple rays will each be refracted to another point. A part of the light, as refracted, will be transmitted, but a part will also be reflected; the red rays at the point O, and the others at certain other points, agreeably to their angle of refraction.

It is very evident, that if the spectator's eye is placed in the direction of M W, or the course of the red making rays, he will only distinguish the red colour; if in another station, he will see only by the yellow rays; in another, by the blue, &c.: but as in a shower of rain there are drops at all heights and all distances, all those that are in a certain position with respect to the spectator will reflect the red rays, all those in the next station the orange, those in the next the green, &c.

To avoid confusion let us for the present imagine only three drops of rain, and three degrees of colours in the section of a bow (Fig. 54.) It is evident that the angle C D E is less than the angle B D E, B D E, and that the angle A D E is the greateſt of the three. This largeſt angle then is formed by the red rays, the middle one conſiſts of the green, and the ſmalleſt is the purple. All the drops of rain, therefore, that happen to be in a certain poſition to the eye of the ſpectator, will reflect the red rays, and form a band or ſemicircle of red; thoſe again in a certain poſition will preſent a band of green, &c. If he alters his ſtation, the ſpectator will ſtill ſee a bow, though not the ſame bow as before; and if there are many ſpectators they will each ſee a different bow, though it appears to be the ſame.

There are ſometimes ſeen two bows, one formed as has been deſcribed, the other appearing externally to embrace the primary bow, and which is ſometimes called a ſecondary or falſe bow, becauſe it is fainter than the other; and what is moſt remarkable is, that in the falſe bow the order of the colours appears always reverſed.

In the true or primary bow, we have ſeen that the rays of light arrive at the ſpectator's eye after two refractions and one reflection; in the ſecondary bow, on the other hand, the rays are ſent to our eyes after two refractions and two reflections, and the order of the colours is reverſed, becauſe in this latter caſe the light enters at the inferior part of the drop, and is tranſmitted through the ſuperior. Thus (Fig. 55.) the ray of light which enters at B is refracted to O, whence it is reflected to P, and again reflected to W, where, ſuffering another refraction, it is ſent to the eye of the ſpectator. The colours of this outer bow are fainter than thoſe of the other, becauſe, the drop being tranſparent, a part of the light is tranſmitted, and conſequently loſt, at each reflection.

The phenomenon aſſumes a ſemicircular appearance, becauſe it is only at certain angles that the refracted rays are viſible to our eyes. The leaſt refrangible, or red rays, make an angle of forty-two degrees two minutes, and the moſt refrangible or violet rays an angle of forty degrees ſeventeen minutes. Now if a line is drawn horizontally from the ſpectator's eye, it is evident that angles formed with this line, of a certain dimenſion in every direction, will produce a circle, as will be evident by only attaching a cord of a given length to a certain point, round which it may turn as round its axis, and in every point will deſcribe an angle with the horizontal line of a certain and determinate extent.

Let H O, for inſtance (Fig. 53.) repreſent the horizon, B W a drop of rain at any altitude, S B a line drawn from the ſun to the drop, which will be parallel to a line S M drawn from the eye of the ſpectator to the ſun. The courſe of part of the decompounded ray S B may be firſt by refraction from B to O, then by reflection from O to W, laſtly by refraction from W to M. Now all drops, which are in ſuch a ſituation that the incident and emergent rays S B, M W produced through them make the ſame angle, S N M will be the means of exciting in the ſpectators

tors the same idea of colour *. Let M W turn upon H O as an axis till W meets the horizon on both sides, and the point W will describe the arc of a circle, and all the drops placed in its circumference will have the property we have mentioned, of transmitting to the eye a particular colour. When the plane H M W O is perpendicular to the horizon, the

* Half the angle between the incident and emergent rays is equal to the difference between *m* times the angle of refraction and the angle of incidence; *m* being equal to the number of reflections added to unity. $BCL = CBN + CNB$, and also $BCK = COB + CBO = 2.\,CBO$.

$\therefore CBN + CNB = 2.\,CBO.$

$\therefore CNB = 2.\,CBO - CBN.$

C N B is half the angle between the incident and emergent rays, and $2 = m$, there being in this case only one reflection; and by pursuing the enquiry in the same manner when the number of reflections is increased, it will appear that C N B always equals $m.\ CBO - CBN$.

This angle C N B, if the angle of incidence increases from nothing, first increases and then decreases, therefore $m\,CBO - CBN$ will in some place be a maximum; that is, where *m* times the fluxion of C B O, is equal to the fluxion of C B N.

Let $CBO = A$ and $CBN = B$.

$\therefore \dot{A} : \dot{B} :: 1 : m$

and radius being equal to unity

$$\dot{A} : \dot{B} :: \frac{\dot{S}A}{\text{cos. } A} : \frac{\dot{S}B}{\text{cos. } B} :: \frac{SA}{\text{cos. } A} : \frac{SB}{\text{cos. } B}$$

but $\text{tang. } A : \text{tang } B :: \frac{S.\,A}{\text{cos. } A} : \frac{S.\,B}{\text{cos. } B.}$

$\therefore \text{Tang. } A : \text{tang. } B :: 1 : m$

 Hence

the line M W is directed to the vertex of the bow, and W K is its altitude.

This

Hence the problem is reduced to a queſtion to find two angles whoſe ſines and tangents ſhall be to each other in a given ratio.

Let $x =$ coſ. of A.

$y =$ coſ. of B.

$\therefore \sqrt{1 - x^2} =$ ſine A, and $\dfrac{\sqrt{1 - x^2}}{x} = \text{T A}.$

$\sqrt{1 - y^2} =$ ſine B, $\dfrac{\sqrt{1 - y^2}}{y} = \text{T B}$

$$1 - x^2 : 1 - y^2 :: R^2 : I^2$$

$$\frac{1 - x^2}{x^2} : \frac{1 - y^2}{y^2} :: 1 : m^2.$$

$$\therefore x^2 : y^2 :: m^2 R^2 : I^2$$

$$\therefore x^2 = \frac{m^2 R^2 y^2}{I^2}$$

$$1 - x^2 = \frac{I^2 - m^2 R^2 y^2}{I^2}$$

$$\therefore \frac{I^2 - m^2 R^2 y^2}{I^2} : 1 - y^2 :: R^2 : I^2$$

$$I^2 - m^2 R^2 y^2 = R^2 - R^2 y^2$$

$$I^2 - R^2 = m^2 R^2 y^2 - R^2 y^2$$

$$\therefore 1 : y :: R \times \sqrt{m^2 - 1} : \sqrt{I^2 - R^2}$$

Hence the coſine of one angle being found, its ſine is given, and from thence the ſine of the other angle, ſince they are in a given ratio to each other.

Thus, according to the nature of the bow, whether primary, ſecondary, &c. the greateſt angle between the incident and emergent rays is found; but in this caſe the rays entering juſt above or below the point where the incident ray makes the greateſt angle between the incident and emergent rays muſt, after emerging from the drop, proceed nearly parallel to each other, and conſequently a number of rays of one colour will

fall

This altitude depends on two things, the angle between the incident and emergent rays, and the height of the sun above the horizon; for since S M is parallel to S N, the angle S N M is equal to N M I, but S M H, the altitude of the sun, is equal to K M I, therefore the altitude of the bow W M K, which is equal to the difference between W M I and K M I, is equal to the difference between the angles made by the incident and emergent rays and the altitude of the sun.

The angle between the incident and emergent rays is different for the different colours, as was already intimated; for the red or least refrangible rays it is equal to 42° 2′; for the violet, or most refrangible, it is equal to 40° 17′; consequently when the sun is more than 42° 2′ above the horizon, the red colour cannot be seen; when it is above 40° 17′, the violet colour cannot be seen.

The secondary bow, as I have said, is made in a similar manner, but the sun's rays suffer, in this case, two reflections within the drop. The ray S B is decompounded at B and one part is refracted to O, thence reflected to P, and from P reflected to W, where it is refracted to M. The angle between the incident and emergent rays S N M is equal as before to N M I, and N M K, the height of the bow, is equal to the difference be-

fall upon the eye, diverging from the point where the angle between the incident and emergent rays is the greatest, and produce the appearance of that colour at the thus determined height in the skies.

tween the angle made by the incident and emergent rays and the height of the ſun. In this caſe the angle S N M, for the red rays, is equal to 50° 7′, and for the violet rays it is equal to 54° 7′; conſequently the upper part of the ſecondary bow will be ſeen only when the ſun is above 54° 7′ above the horizon, and the lower part of the bow will be ſeen only when the ſun is 50° 7′ above the horizon.

In the ſame manner bows might be formed without end by a greater number of reflections within the drops; but as the ſecondary is ſo much fainter than the primary, that all the colours in it are ſeldom ſeen, for the ſame reaſon a bow made with three reflections would be fainter ſtill, and in general altogether imperceptible. Since the rays of light, by various reflections and refractions, are thus capable of forming, by means of drops of rain, the bows which we ſo frequently ſee in the heavens, it is evident that there will be not only ſolar and lunar bows, but that many ſtriking appearances of colours will be made by drops upon the ground, or air on the agitated ſurface of the water. Thus a lunar bow will be formed by rays from the moon affected by drops of rain, but as its light is very faint in compariſon with that of the ſun, ſuch a bow will very ſeldom be ſeen, and the colours of it, when ſeen, will be faint and dim. I was once a ſpectator of a lunar bow, in the courſe of a pedeſtrian expedition by moonlight in the autumnal ſeaſon. The night was uncommonly light, though ſhowery, and the colours

Fig. 54.

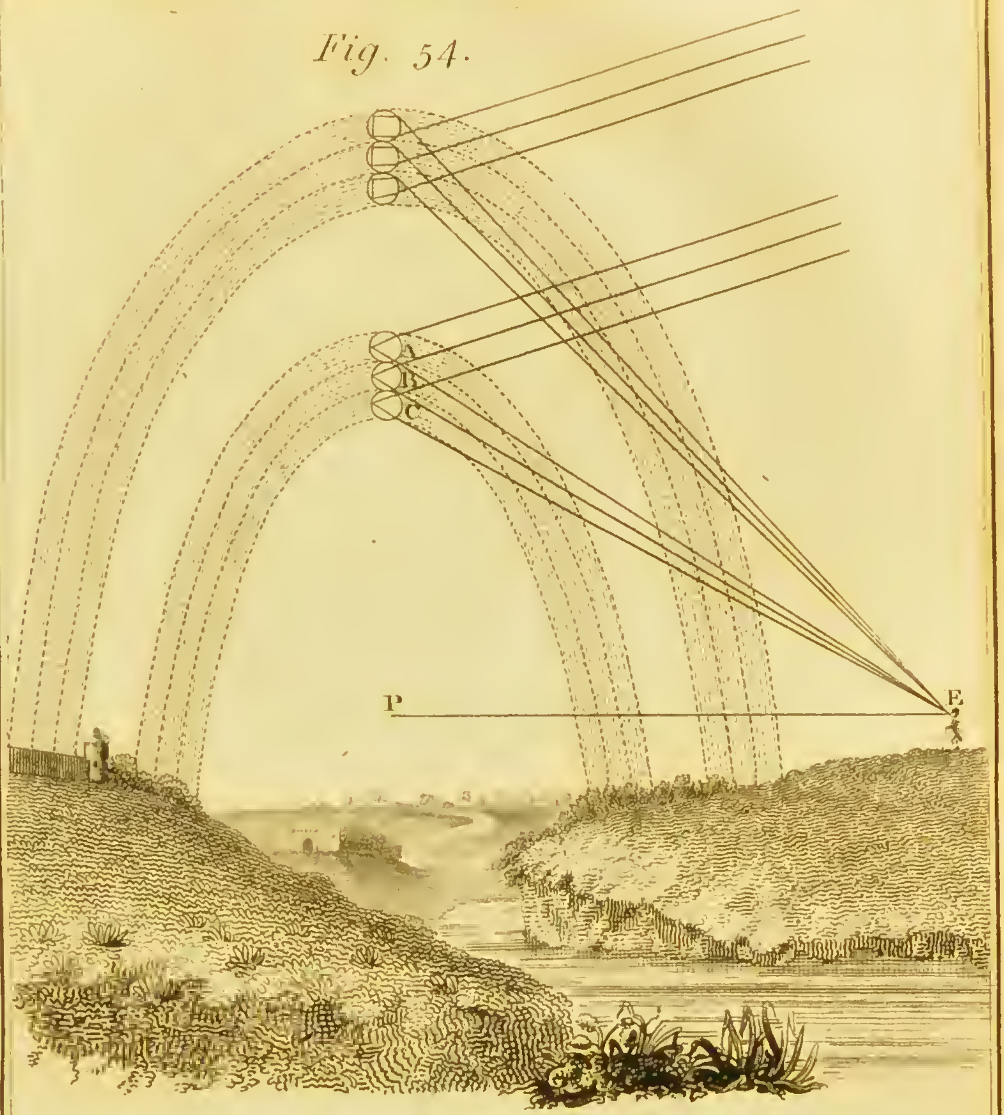
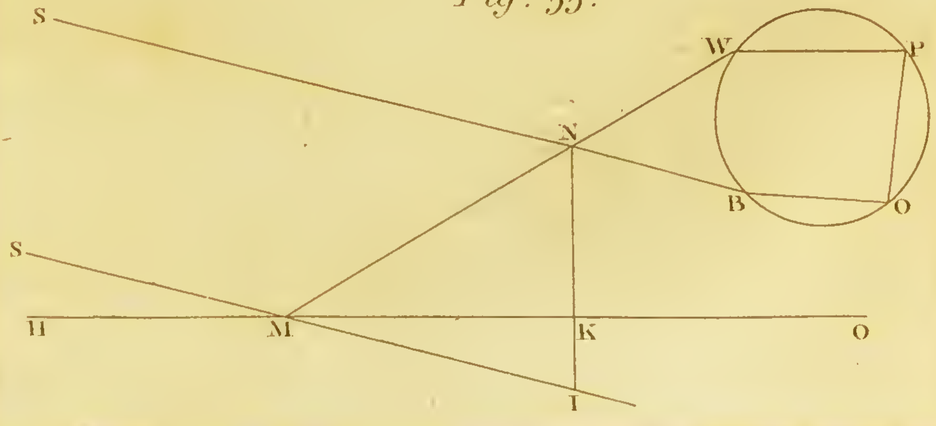


Fig. 55.



lours much more vivid than I could have conceived; indeed I have ſeen rainbows by day not more conſpicuous. There were not, however, ſo many colours diſtinguiſhable as in the ſolar bow.

The marine or ſea bow is a phenomenon ſometimes obſerved in a much agitated ſea; when the wind, ſweeping part of the tops of the waves, carries them aloft, ſo that the ſun's rays, falling upon them, are refracted, &c. as in a common ſhower, and paint the colours of the bow.

Rohault mentions coloured *bows* on the graſs, formed by the refraction of the ſun's rays in the morning dew.

Dr. Langwith, indeed, once ſaw a bow lying on the ground, the colours of which were almoſt as lively as thoſe of the common rainbow. It was extended ſeveral hundred yards. It was not round, but oblong, being, as he conceived, the portion of an hyperbola. The colours took up leſs ſpace, and were much more lively in thoſe parts of the bow which were near him than in thoſe which were at a diſtance.

The drops of rain deſcend in a globular form, and thence we can eaſily acount for the effects produced by them on the rays of light; but in different ſtates of the air, inſtead of drops of rain vapour falls to the earth in different forms of ſleet, ſnow, and hail. In the two latter ſtates there cannot be a refraction of the rays of light, but in the former ſtate, when a drop is partly in a congealed and partly in a fluid form, the rays of light will be differently affected,

fected, both from the form of the drop and its various refracting powers. Hence we may expect a variety of curious appearances in the heavens, and to these drops, in different states, we may attribute the formation of halos, parhelia, and many other phenomena, detailed in the philosophical transactions, or in the histories of every country.

The halo or corona, is a luminous circle surrounding the sun, the moon, a planet, or a fixed star. It is sometimes quite white, and sometimes coloured like the rainbow. Those which have been observed round the moon or stars are but of a very small diameter; those round the sun are of different magnitudes, and sometimes immensely great. When coloured, the colours are fainter than those of the rainbow, and appear in a different order, according to their size. In those which Sir Isaac Newton observed in 1692, the order of the colours, from the inside next the sun, was in the innermost, blue, white, red; in the middle, purple, blue, green, yellow, pale red; in the outermost, pale blue and pale red. Hugens observed one red next the sun, and pale blue at the extremity. Mr. Weidler has given an account of one yellow on the inside and white on the outside. In France one was observed, in which the order of the colours was, white, red, blue, green, and a bright red on the outside *.

Artificial coronas may be made in cold weather, by placing a lighted candle in the midst of a cloud

* Priestley's Hist. of Opt. p. 597.

of

of ſteam; or if a glaſs window is breathed upon, and the flame of a candle placed at ſome diſtance from the window, while the operator is alſo at the diſtance of ſome feet from another part of the window, the flame will be ſurrounded with a coloured halo.

I was once witneſs to a very pleaſing phenomenon. The full moon was partly obſcured behind the ſkirt of a very thin white cloud, which, as it grew thinner towards the edge, had the full effect of a priſm in ſeparating the rays of light, and exhibited the colours of the rainbow in their proper gradations.

When M. Bouguer was on the top of mount Pichinea, in the Cordilleras, he and ſome gentlemen who accompanied him, obſerved a moſt remarkable phenomenon. When the ſun was juſt riſing behind them, and a white cloud was about thirty paces from them, each of them obſerved his own ſhadow (and no other) projected upon it. All the parts of the ſhadow were diſtinct, and the head was adorned with a kind of glory, conſiſting of three or four concentric crowns, of a very lively colour, each exhibiting all the varieties of the primary rainbow, and having the circle red on the outſide.

Similar to this appearance was one which occurred to Dr. M'Fait, in Scotland. This gentleman obſerved a rainbow round his ſhadow in a miſt, when he was ſituated on an eminence above it. In this ſituation the whole country appeared to be immerſed in a vaſt deluge, and nothing but the tops of hills appeared here and there above the flood; at another time he obſerved a double range of colours round his ſhadow *.

The parhelia, or mock ſuns, are the moſt ſplendid phenomena of this kind. We find theſe appearances frequently adverted to by the ancients, who generally conſidered them as formidable omens. Four mock ſuns were ſeen at once by Scheiner at Rome, and by Muſchenbroeck at Utrecht; and ſeven were obſerved by Hevelius at Sedan, in 1661 †.

The parhelia generally appear about the ſize of the true ſun, not quite ſo bright, though they are ſaid ſometimes to rival their parent luminary in ſplendor. When there are a number of them they are not equal to each other in brightneſs. Externally they are tinged with colours like the rainbow. They are not always round, and have ſometimes a long fiery tail oppoſite the ſun, but paler towards the extremity. Dr. Halley obſerved one with tails extending both ways. Mr. Weidler ſaw a parhelion with one tail pointing up and another downwards, a little crooked; the limb which was fartheſt from the ſun being of a purple colour, the other tinged with the colours of the rainbow ‡.

Coronas generally accompany parhelia, ſome coloured and others white. There is alſo in general a very large white circle, parallel to the horizon,

* Prieſtley's Opt. p. 600.

† Prieſtley's Hiſt. Opt. p. 613. ‡ Ib. p. 614.

which paſſes through all the parhelia; and, if it was entire, would go through the center of the ſun; ſometimes there are arches of ſmaller circles concentric to this, and touching the coloured circles which ſurround the ſun; they are alſo tinged with colours, and contain other parhelia.

One of the moſt remarkable appearances of this kind was that which was obſerved at Rome by Scheiner, as intimated above, and this may ſerve as a ſufficient inſtance of the parhelion.

This celebrated phenomenon is repreſented in Pl. XV. Fig. 56. in which A is the place of the obſerver, B his zenith, C the true ſun, A B a plane paſſing through the obſerver's eye, the true ſun, and the zenith. About the ſun C, there appeared two concentric rings, not compleat, but diverſified with colours. The leſſer of them, D E F, was fuller, and more perfect; and though it was open from D to F, yet thoſe ends were perpetually endeavouring to unite, and ſometimes they did ſo. The outer of theſe rings was much fainter, ſo as ſcarcely to be diſcernible. It had, however, a variety of colours, but was very inconſtant. The third circle, K L M N, was very large, and all over white, paſſing through the middle of the ſun, and every where parallel to the horizon. At firſt this circle was entire; but towards the end of the phenomenon it was weak and ragged, ſo as hardly to be perceived from M towards N.

In the interſection of this circle, and the outward iris G K I, there broke out two parhelia, or mock

ſuns,

ſuns, N and K, not quite perfect, K being rather weak, but N ſhone brighter and ſtronger. The brightneſs of the middle of them was ſomething like that of the ſun, but towards the edges they were tinged with colours like thoſe of the rainbow, and they were uneven and ragged. The parhelion N was a little wavering, and ſent out a ſpiked tail N P, of a colour ſomewhat fiery, the length of which was continually changing.

The parhelia at L and M, in the horizontal ring, were not ſo bright as the former, but were rounder, and white, like the circle in which they were placed. The parhelion N diſappeared before K; and while M grew fainter, K grew brighter, and vaniſhed the laſt of all.

It is to be obſerved farther, that the order of the colours in the circles D E F, G K N was the ſame as in the common halo's, namely red next the ſun, and the diameter of the inner circle was alſo about 45 degrees; which is the uſual ſize of a halo.

Parhelia have been ſeen for one, two, three, and four hours together; and in North America they are ſaid to continue ſome days, and to be viſible from ſun riſe to ſun ſet. When they diſappear, it ſometimes rains, or ſnow falls in the form of oblong ſpiculæ *.

Mr. Wales ſays, that at Churchhill, in Hudſon's Bay, the riſing of the ſun is always preceded by two long ſtreams of red light. Theſe riſe as the ſun riſes; and as they grow longer begin to bend

* Prieſtley's Hiſt. Opt. p. 614 to 617.

towards

towards each other, till they meet directly over the ſun, forming there a kind of parhelion or mock ſun.

Theſe two ſtreams of light, he ſays, ſeem to have their ſource in two other parhelia, which riſe with the true ſun; and in the winter ſeaſon, when the ſun never riſes above the haze or fog, which he ſays is conſtantly found near the horizon, all theſe accompany him the whole day, and ſet with him in the ſame manner as they riſe. Once or twice he ſaw a fourth parhelion under the true ſun, but this, he adds, is not common.*

The cauſe of theſe is apparently the reflection of the ſun's light and image from the thick and frozen clouds in the northern atmoſphere, accompanied alſo with ſome degree of refraction. To enter upon a mathematical analyſis of theſe phenomena would be only tedious, and very foreign to our purpoſe. From what has been ſaid upon this ſubject it is evident, that all the phenomena of colours depend upon two properties of light, the refrangibility and reflexibility of its rays.

The blue colour of the atmoſphere has been beautifully accounted for by Mr. Delaval, in the experiments already noticed. The atmoſphere he conſiders as a ſemi-pellucid medium, which abounds in volatile and evaporable particles, diſengaged from natural bodies by ſeveral operations, as fermentation, effervescence, putrefaction, &c. Theſe particles

* Prieſtley's Hiſt. Opt. p. 617.

differ

differ greatly in denſity, &c. from the air, and, as they reflect a white light, may be conſidered as ſo many white particles diffuſed through the pellucid colourleſs air. In this reſpect the atmoſphere is ſimilar to the ſemi-pellucid medium, which is formed by a mixture of arſenic with glaſs. In both theſe ſubſtances, whilſt the white particles are rarely diſſeminated through the tranſparent medium, the leſs refrangible rays are tranſmitted through the intervals which intercede the particles *, but the more refrangible rays are intercepted and reflected by the particles, and the mixture of thoſe rays produces a blue colour.

In air, as well as in the ſolid ſemi-pellucid media, when the white particles are more denſely arranged, the intervals which intercede them are diminiſhed, and in this ſtate of the atmoſphere a great proportion of all the rays are reflected, ſo as to produce the effect of perfect whiteneſs, or at leaſt an approach towards it. Thus, when the part of the atmoſphere, which is near the ſurface of the earth, is occupied by groſs vapours, this mixture of air with aqueous or other particles is white: ſuch is the common appearance of fogs. When ſuch vapours are elevated high in the atmoſphere, and form

* On this account, diſtant mountains covered with ſnow (which it is well known reflect all the rays of the ſun) appear, when the air is thick, and the ſun nearly oppoſite them, of a warmer colour than they otherwiſe would, and more approaching to yellow or orange.

clouds, they reflect the white light of the fun, and appear white, whenever its incident rays fall on them entire and undivided; and as the reflecting particles are not equally diffufed through every part of the pellucid air, of which the atmofphere principally confifts, it frequently happens that large tracts of air are only furnifhed with fuch a portion as qualify them to reflect a blue colour, while others are fo denfely ftored as to form clouds.

Of the red and vivid colour of the morning and evening clouds Mr. Melville has fuggefted a caufe upon fimilar principles, which we muft at leaft allow is ingenious and probable. He fuppofes, as well as Mr. Delaval, that a feparation of the rays is made in paffing through the horizontal atmofphere, and that the clouds reflect and tranfmit the fun's light, as any half tranfparent colourlefs body would do; for as the atmofphere reflects a greater quantity of blue and violet rays than of the reft, the fun's light tranfmitted through it inclines towards yellow, orange, or red, efpecially when it paffes through a long tract of air; and in this manner the fun's horizontal light is tinctured with a deep orange, and even red, and the colour becomes ftill deeper after fun-fet; hence he concludes, that the clouds, according to their different altitudes, may affume all the variety of colours at fun rifing and fetting, by barely reflecting the fun's incident light as they receive it.

The green colour of the fea may alfo be accounted-for in the fame manner. Sir Ifaac Newton, and others, have fuppofed that this effect was produced by the reflective power of the water; but that this is not the case is manifest; for when sea water is admitted into a reservoir, which does not exceed a few inches in depth, it appears pellucid and colourless.

Dr. Halley, in the diving-bell *, observed, that when he was sunk many fathoms deep into the sea, the upper part of his hand, on which the sun shone directly through the water, was red, and the lower part a blueish green. On these phenomena Mr. Delaval observes, that the sea water abounds with heterogeneous particles, many of which approach so near in density to the water itself, that their reflective power must be very weak, though, as they are not quite of the same density, they still must have some degree of reflective power. Although these, therefore, may be invisible when separately viewed, yet when the forces of a great number of such minute bodies are united, their action on the rays of light becomes perceptible, some rays being reflected by them, whilst others are transmitted through their intervals, according to the quantity of reflective matter which the rays arrive at in the internal parts of the water.

The opacity of the sea, caused by the numerous reflections from its internal parts, is so considerable, that it is not near so transparent as other water; the reflective particles, therefore, which are dispersed through the mass of sea water, have consequently a

* Newton's Opt. l. 1. Part 2d.

greater

greater reflective power than thofe which are difperfed through the atmofphere. Inftead, therefore, of reflecting a delicate blue, fuch as that of the fky, the fea water, by acting upon a greater portion of the more refrangible rays, exhibits a green colour, which we know to be a middle colour produced by the mixture of blue rays with fome of the lefs refrangible, as the yellow or orange.

With refpect to the phenomena remarked by Dr. Halley, it is eafy to conceive that the light, when ftripped of all the more refrangible rays, fhould produce a rofe colour, fuch as that he obferved on the upper part of his hand; on the contrary, that which illuminated the lower part of his hand confifted partly of rays reflected from the ground, and partly of thofe which were reflected from the internal parts of the fea water, which, we have feen, are chiefly blue and violet; and the mixture of thefe produced the greenifh tinge which the Doctor remarked *, and which common experience fhews is the predominant colour of the ocean.

* Delaval on the caufes of colours in opake bodies, v. ii. Manch. Mem.

Chap. X.

OF THE INFLECTION OF LIGHT.

Retrospect of the Doctrine of Reflection.—Nature of Inflection.—Newton's Experiments.—Analogy between this Property and Refraction.—Curious Effects from this Property.

THE direction of the rays of light is changed, as we have seen, in their approach to certain bodies, by reflection and refraction, and consequently we must admit that there is some power in these bodies by which such effects are universally produced. If reflection was produced simply by the impinging of particles of light on hard or elastic bodies, or if they were in themselves elastic, the same effects would follow as in the impulse of other elastic bodies; but the angle of incidence could not be equal to the angle of reflection, unless the particles of light were perfectly elastic, or the bodies on which they impinged were perfectly elastic. Now we know that the bodies on which these particles impinge are not perfectly elastic, and also that if the particles of light were perfectly elastic, the diffusion of light from the reflecting bodies would be very different from its present appearance; for as no body can be perfectly polished, the particles of light which are so inconceivably small would be reflected

reflected back by the inequalities on the ſurface in every direction; conſequently we are led to this concluſion, that the reflecting bodies have a power which acts at ſome little diſtance from their ſurfaces.

If this reaſoning is allowed to be juſt, it neceſſarily follows, that if a ray of light, inſtead of impinging on a body, ſhould paſs ſo near to it as to be within the ſphere of that power which the body poſſeſſes, it muſt neceſſarily ſuffer a change in its direction. Actual experiments confirm the truth of this poſition, and to the change in the direction of a particle of light, owing to its nearneſs to a body, we give the name of inflection.

From one of theſe experiments, made by Sir Iſaac Newton, the whole of this ſubject will be eaſily underſtood. At the diſtance of two or three feet from the window of a darkened room, in which was a hole three-fourths of an inch broad, to admit the light, he placed a black ſheet of paſteboard, having in the middle a hole about a quarter of an inch ſquare, and behind the hole the blade of a ſharp knife, to intercept a ſmall part of the light which would otherwiſe have paſſed through the hole. The planes of the paſteboard and blade were parallel to each other, and when the paſteboard was removed at ſuch a diſtance from the window, as that all the light coming into the room muſt paſs through the hole in the paſteboard, he received what came through this hole on a piece of paper two or three feet beyond the knife, and perceived two ſtreams of faint light ſhooting out both ways from the beam of light into the ſhadow. As the brightneſs of the direct rays obſcured the fainter light, by making a hole in his paper he let them paſs through, and had thus an opportunity of attending cloſely to the two ſtreams, which were nearly equal in length, breadth, and quantity of light. That part which was neareſt to the ſun's direct light was pretty ſtrong for the ſpace of about a quarter of an inch, decreaſing gradually till it became imperceptible, and at the edge of the knife it ſubtended an angle of about twelve or at moſt fourteen degrees.

Another knife was then placed oppoſite to the former, and he obſerved, that when the diſtance of their edges was about the four hundredth part of an inch, the ſtream divided in the middle, and left a ſhadow between the two parts, which was ſo dark, that all light paſſing between the knives ſeemed to be bent aſide to one knife or the other; as the knives were brought nearer to each other, this ſhadow grew broader, till upon the contact of the knives the whole light diſappeared.

Purſuing his obſervations upon this appearance, he perceived fringes, as they may be termed, of different coloured light, three made on one ſide by the edge of one knife, and three on the other ſide by the edge of the other, and thence concluded, that as in refraction the rays of light are differently acted upon, ſo are they at a diſtance from bodies by inflection; and by many other experiments of the

ſame

Fig. 56.

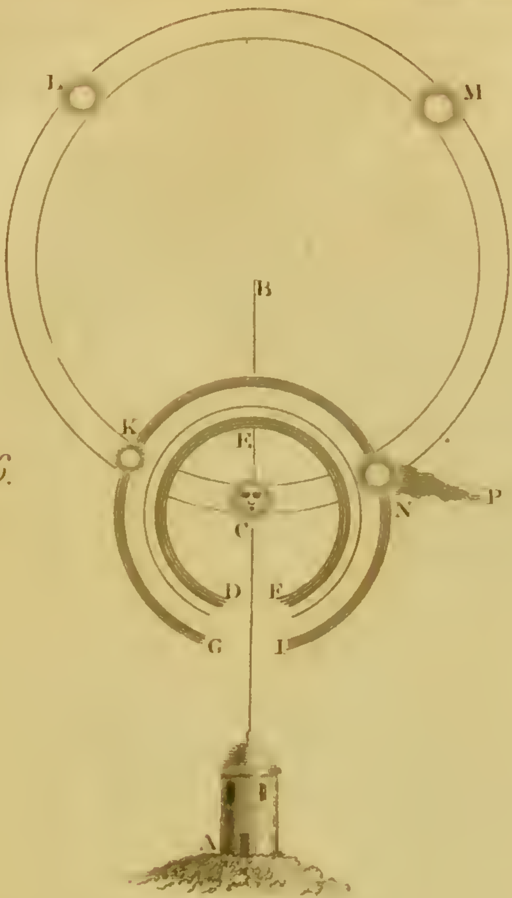


Fig. 57.

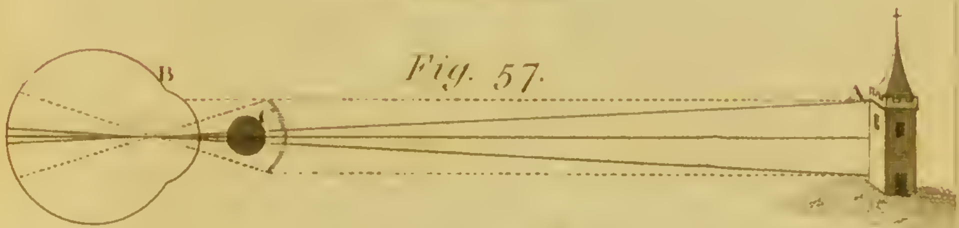
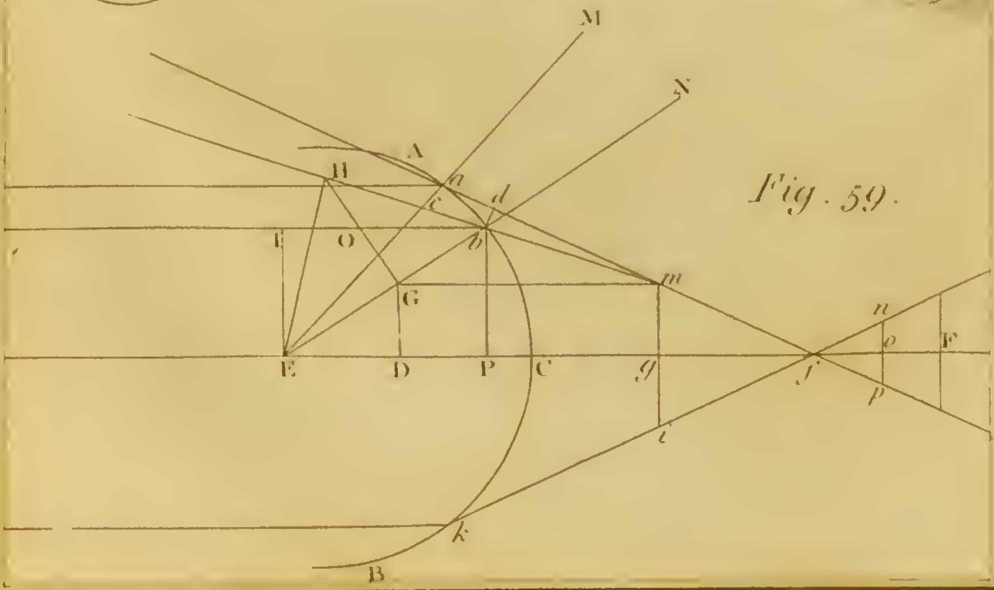


Fig. 59.



ſame kind he ſupported his poſition, which is confirmed by all ſubſequent experiments.

We may naturally conclude, that from this property of inflection ſome curious changes will be produced in the appearances of external objects. If we take a piece of wire of a leſs diameter than the pupil of the eye and place it between the eye and a diſtant object, the latter will appear magnified (Fig. 57.) Let A be a church ſteeple, B the eye, C the wire. The rays by which the ſteeple would have been otherwiſe ſeen are intercepted by the wire, and it is now ſeen by inflected rays, which make a greater angle than the direct rays, and conſequently the ſteeple will be magnified.

In nearly ſhutting the eyes, and looking at a candle, there appear rays of light extending from it in various directions, like comets' tails; for the light, in paſſing through the eye-laſhes, is inflected, and conſequently many ſeparate beams will be formed, diverging from the luminous object. The power of bodies to inflect the rays of light paſſing near to them will produce different effects, according to the nature of the rays acted upon; conſequently a ſeparation will take place in the differently refrangible rays, and thoſe fringes, which were taken notice of by Sir Iſaac Newton, will appear in other objects which are ſeen by the means of inflected rays. From conſidering thus the action of bodies upon light, we come to this general concluſion, for which we are indebted to our great philoſopher, that light, as well as all other matter, is acted upon at a diſtance; and that reflection, refraction, and inflection, are owing to certain general laws in the particles of matter, which are equally neceſſary for the preſervation of the beautiful harmony in the objects neareſt to us, as to produce by their joint action that great law by which the greater bodies in their ſyſtem are retained in their reſpective orbits.

Book

BOOK IV.

OF ELECTRICITY.

CHAP. I.

HISTORY OF DISCOVERIES RELATIVE TO ELECTRICITY.

Origin of the Name.—How far Electricity was known to the Ancients.—Mr. Boyle.—Otto Guericke.—Dr. Wall.—Mr. Hawkſbee.—Mr. Grey's Diſcoveries.—M. Du Fay's.—Subſequent Diſcoveries of Mr. Grey.—Improvements of German Philoſophers.—Leyden Phial.—Electrical Battery.—Spirits fired by Electricity conducted through the River Thames.—Two Species of Electricity diſcovered.—Dr. Franklin's great Diſcoveries.

THE attractive power which amber, and other electric bodies, acquire by friction, was long known to philoſophers; and it is unneceſſary to remark, that this branch of ſcience derives its name from ελεκτρον (electron) the Greek word for amber. The other electric properties were ſlowly diſcovered. Mr. Boyle was the firſt who had a glimpſe of the electric light; as he remarked, after rubbing ſome diamonds in order to give them the power of attraction, that they afforded light in the dark.

Otto

Otto Guericke, burgomaſter of Madgeburg, made an electric globe of ſulphur, and by whirling it about in a wooden frame, and rubbing it at the ſame time with his hand, he performed various electrical experiments. He added to the ſtock of knowledge the diſcovery, that a body once attracted by an excited electric was repelled by it, and not attracted again till it had touched ſome other body. Thus he was able to keep a feather ſuſpended in the air over his globe of ſulphur; but he obſerved, if he drove it near a linen thread, or the flame of a candle, it inſtantly recovered its propenſity (if I may uſe the expreſſion) for approaching the globe again. The hiſſing noiſe, and the gleam of light which his globe afforded, both attracted his notice.

Theſe circumſtances were, however, afterwards accurately remarked by Dr. Wall, who, by rubbing amber upon a woollen ſubſtance in the dark, found alſo that light was produced in conſiderable quantities, accompanied with a crackling noiſe; and what is ſtill more extraordinary, he adds, "this light and crackling ſeems, in ſome degree, to repreſent thunder and lightning."

Mr. Hawkſbee firſt obſerved the great electric power of glaſs. He conſtructed a wooden machine, which enabled him conveniently to put a glaſs globe in motion. He confirmed all the experiments of Dr. Wall. He obſerved, that the light emitted by the friction of electric bodies, beſides the crackling noiſe, was accompanied by an acute

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ſenſe of feeling when applied to his hand. He ſays, that all the powers of electricity were improved by warmth, and diminiſhed by moiſture.

Hitherto the diſtinction between thoſe bodies which are capable of being excited to electricity and thoſe which are only capable of receiving it from the others, appears ſcarcely to have been ſuſpected. About the year 1729, this great diſcovery was made by Mr. Grey, a penſioner of the Charter-Houſe. After ſome fruitleſs attempts to make metals attractive by heating, rubbing, and hammering, he conceived a ſuſpicion, that as a glaſs tube, when rubbed in the dark, communicated its light to various bodies, it might poſſibly at the ſame time communicate its power of attraction to them. In order to put this to the trial, he provided himſelf with a tube three feet five inches long, and near an inch and one fifth in diameter; the ends of the tube were ſtopped by cork; and he found that when the tube was excited, a down feather was attracted as powerfully by the cork as by the tube itſelf. To convince himſelf more completely, he procured a ſmall ivory ball, which he fixed at firſt to a ſtick of fir four inches long, which was thruſt into the cork, and found that it attracted and repelled the feather even with more vigour than the cork itſelf. He afterwards fixed the ball upon long ſticks, and upon pieces of braſs and iron wire, with the ſame ſucceſs; and laſtly, attached it to a long piece of packthread, and hung it from a high balcony, in which ſtate he found,

found, that by rubbing the tube the ball was conſtantly enabled to attract light bodies in the court below.

His next attempt was to prove, whether this power could be conveyed horizontally as well as perpendicularly; with this view he fixed a cord to a nail which was in one of the beams of the ceiling, and making a loop at that end which hung down, he inſerted his packthread, with the ball which was at the end of it, through the loop of the cord, and retired with the tube to the other end of the room; but in this ſtate he found that his ball had totally loſt the power of attraction. Upon mentioning his diſappointed efforts to a friend, it was ſuggeſted, that the cord which he had uſed to ſupport his packthread might be ſo coarſe as to intercept the electric powers, and they accordingly attempted to remedy this evil by employing a ſilk ſtring, which was much ſtronger in proportion than a hempen cord. With this apparatus the experiment ſucceeded far beyond their expectations. Encouraged by this ſucceſs, and attributing it wholly to the fineneſs of the ſilk, they proceeded to ſupport the packthread, to which the ball was attached, by very fine braſs and iron wire, but, to their utter aſtoniſhment, found the effect exactly the ſame as when they uſed the hempen cord; the electrical virtue utterly paſſed away; while on the other hand, when the packthread was ſupported by a ſilken cord, they were able to convey the electric virtue ſeven hundred and ſixty-five feet.

It

It was evident, therefore, that theſe effects depended upon ſome peculiar quality in the ſilk, which diſabled it from conducting away the electrical power, as the hempen cord and the wire had done. This, probably, immediately led to the diſcovery of other non-conducting bodies, and *hair*, *roſin*, *glaſs*, &c. were preſently made uſe of to inſulate the bodies which were electrified. The next obvious improvement was to electrify ſeparate bodies, by placing them upon non-conductors; and in this manner Mr. Grey and his friend Mr. Wheeler electrified a large map, a table cloth, &c. &c. In the latter end of the ſame ſummer, Mr. Grey found that he could electrify a rod as well as a packthread, without inſerting any part into his excited tube, and that it only required to be placed nearly in contact with the apparatus.

Mr. Grey proceeded to try the effects of electricity upon animal bodies. He ſuſpended a boy on hair lines in a horizontal poſition, and bringing the excited tube near his feet, he found that leaf braſs was attracted very vigorouſly by the head of the boy. He found alſo, that he could communicate electricity to fluid bodies, by inſulating them upon a cake of roſin; and obſerved, that when an excited tube was held over a cup of water, the water was preſently attracted, in a conical form, towards the tube; that the electric matter paſſed from the tube to the water with a ſlight flaſh and a crackling noiſe; and that the fluid ſubſided with a tremulous and waving motion.

After

After this period the ſpirit of philoſophy in this branch was no longer confined to England. M. Du Fay, intendant of the French king's gardens, added to the ſtock of diſcoveries. He found that all bodies, except metallic, ſoft, and fluid ones, might be made electric by firſt heating them, and then rubbing them on any ſort of cloth. He alſo excepts thoſe ſubſtances which grow ſoft by heat, as gums, or which diſſolve in water, as glue. In purſuing Mr. Grey's experiments with a packthread, &c. he perceived that they ſucceeded better by wetting the line. To prove the effects of this wonderful agent on the animal body, he ſuſpended himſelf by ſilk cords, as Mr. Grey had ſuſpended the boy, and in this ſituation he obſerved, that as ſoon as he was electrified, if another perſon approached him, and brought his hand, or a metal rod, within an inch of his body, there immediately iſſued from it one or more prickling ſhoots, attended with a ſnapping noiſe; and he adds, that this experiment occaſioned a ſimilar ſenſation in the perſon who placed his hand near him: in the dark he obſerved, that theſe ſnappings were occaſioned by ſo many ſparks of fire.

Mr. Grey, on reſuming his experiments, immediately concluded from that of M. Du Fay, in which a piece of metal drew ſparks from the perſon electrified, and ſuſpended on ſilk lines, that if the perſon and the metal changed places the effect would be the ſame. He accordingly ſuſpended a piece of metal by ſilk threads near his excited tube, and

and found he drew ſparks from it at pleaſure. This was the origin of metallic conductors. Mr. Grey ſuſpected that the electric fire might be of the ſame nature with thunder and lightning.

To the philoſophers of Germany we are indebted for moſt of the improvements in the electrical apparatus. They revived the uſe of the globe, which had been invented by Mr. Hawkſbee, which was afterwards ſuperſeded by a cylinder, and to which they imparted a circular motion by means of wheels, and uſed a woollen rubber inſtead of the hand. By the great force alſo of their machines, they were able to fire ſome of the moſt inflammable ſubſtances, ſuch as highly rectified ſpirits, by the electric ſpark.

But the moſt ſurprizing diſcovery was that which immediately followed theſe attempts, in the years 1745–6; I mean the method of accumulating the electric power by the Leyden phial. M. Von Kleiſt, dean of the cathedral of Camnin, was the firſt who found that a nail or braſs wire, confined in an apothecary's phial, and expoſed to the electrifying glaſs or prime conductor, had a power of collecting the electric virtue ſo as to produce the moſt remarkable effects; he ſoon found that a ſmall quantity of fluid added to it increaſed the power; and ſucceſſive electricians found, that fluid matter, or any conducting body confined in a glaſs veſſel, had this power of accumulating and condenſing (if I may uſe the expreſſion) the electric virtue. The ſhock which an electrician is enabled to give by means of

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the Leyden phial is well known; and this was soon followed by another improvement, that of forming what is called the electric battery, by increasing the number of phials, by which means the force is proportionably increased. By these means the electric shock was tried upon the brute creation, and proved fatal to many of the smaller animals, which appeared as if killed by lightning. By these means also the electric matter was conveyed to great distances; by the French philosophers, for near three miles; and by Dr. Watson, and some other members of the Royal Society, it was conveyed, by a wire, over the river Thames, and back again through the river, and spirits were kindled by the electric fire which had passed through the river. In another experiment by the same gentleman, it was found that the electric matter made a circuit of about four miles almost instantaneously.

The next discovery respects the nature, or rather the origin, of the electric matter. Dr. Watson was first induced to suspect that the glass tubes and globes did not contain the electric power in themselves, by observing, that upon rubbing the glass tube while he was standing on cakes of wax (in order to prevent, as he expected, any of the electric matter from discharging itself through his body on the floor) the power was so much lessened that no snapping could be observed upon another person's touching any part of his body; but that if a person not electrified held his hand near the tube while it was rubbed, the snapping was

very

very ſenſible. The event was the ſame when the globe was whirled in ſimilar circumſtances; for if the man who turned the wheel, and who, together with the machine, was ſuſpended upon ſilk, touched the floor with one foot, the fire appeared upon the conductor; but if he kept himſelf free from any communication with the floor, no fire was produced. From theſe and other deciſive experiments Dr. Watſon concludes, that theſe globes and tubes are no more than the firſt movers or determiners of the electric power.

M. Du Fay had made a diſtinction of two different ſpecies of electricity, one of which he called the *vitreous*, and the other the *reſinous* electricity; and ſoon after the diſcovery of the Leyden phial, it was found, that by coating the outſide of the phial with a conducting ſubſtance, which communicated by a wire with the perſon who diſcharged the phial, the ſhock was immenſely increaſed; and indeed it appeared, that the phial could not be charged unleſs ſome conducting ſubſtance was in contact with the outſide. Dr. Franklin, however, was the firſt who explained theſe phenomena. He ſhewed that the ſurplus of electricity, which was received by one of the coated ſurfaces of the phial, was actually taken from the other; and that one was poſſeſſed of leſs than its natural ſhare of the electric matter, while the other had a ſuperabundance. Theſe two different ſtates of bodies, with reſpect to their portion of electricity, he diſtinguiſhed by the terms *plus* or poſitive, and *minus* or negative; and it was inferred from the appearances, that bodies which exhibited what M. Du Fay called the reſinous electricity, were in the ſtate of *minus*, that is, in the ſtate of attracting the electric matter from other bodies, while thoſe which were poſſeſſed of the vitreous electricity were bodies electrified *plus*, or in a ſtate capable of imparting electricity to other bodies. By this diſcovery Dr. Franklin was enabled to increaſe the electric power almoſt at pleaſure, namely, by connecting the outſide of one phial with the inſide of another, in ſuch a manner that the fluid which was driven out of the firſt would be received by the ſecond, and what was driven out of the ſecond would be received by the third, &c. and this conſtitutes what we now call an electrical battery.

But the moſt aſtoniſhing diſcovery which Franklin, or I might ſay any other perſon, ever made in this branch of ſcience, was the demonſtration of what had been ſlightly ſuſpected by others, the perfect ſimilarity, or rather identity, of lightning and electricity. The Doctor was led to this diſcovery by comparing the effects of lightning with thoſe of electricity, and by reflecting, that if two gun-barrels electrified will ſtrike at two inches, and make a loud report, what muſt be the effect of ten thouſand acres of electrified cloud. Not ſatisfied, however, with ſpeculation, he conſtructed a kite with a pointed wire fixed upon it, which, during a thunder ſtorm, he contrived to ſend

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up into an electrical cloud. The wire in the kite attracted the lightning from the cloud, and it descended along the hempen string, and was received by a key tied to the extremity of it, that part of the string which he held in his hand being of silk, that the electric virtue might stop when it came to the key. At this key he charged phials, and from the fire thus obtained he kindled spirits, and performed all the common electrical experiments.

Dr. Franklin, after this discovery, constructed an insulated rod to draw the lightning from the atmosphere into his house, in order to enable him to make experiments upon it; he also connected with it two bells, which gave him notice by their ringing when his rod was electrified. This was the origin of the metallic conductors now in general use.

Mr. Canton afterwards discovered, that the positive and negative electricity, which were supposed to depend upon the nature of the excited body, and therefore had obtained the names of resinous and vitreous, depended chiefly upon the nature of the surface; for that a glass tube, when the polished surface was destroyed, exhibited proofs of negative electricity as much as sulphur or sealing wax, and drew sparks *from* the knuckle when applied to it, instead of giving fire from its own body; when the tube was greased, and a rubber with a rough surface was applied to it, its positive power was restored, and the contrary, when the rubber became smooth by friction.

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At this period it may not be improper to cloſe my ſketch of the diſcoveries relating to electricity; ſince the ſole object of theſe narratives, in this work, is to conduct the reader to a more ready apprehenſion of the ſcience, it would be uſeleſs to lead him into the minutiæ of it before he was made properly acquainted with the general principles.

CHAP. II.

GENERAL PRINCIPLES OF ELECTRICITY.

Analogy between Caloric, or Fire, and the electrical Fluid.—The Arguments on the contrary Side.—Conjectures concerning the Nature of this Fluid.—Means of producing electrical Phenomena.—Conductors and Non-conductors.—Instruments employed in Electricity.

FROM the brief account, which has been given, in the preceding chapter, of discoveries relative to this extraordinary fluid, the reader will be in a considerable degree prepared to infer, that electricity is the action of a body put in a state to attract or repel light bodies placed at a certain distance; to give a slight sensation to the skin, resembling in some measure that which we experience in meeting with a cobweb in the air; to spread an odour like the phosphorus of Kunkell; to dart pencils of light from the surface, attended with a snapping noise, on the approach of certain substances; lastly, that the body put in this state is capable of communicating to other bodies the power of producing the same effects during a certain time.

The electric power is indubitably the effect of some matter put in motion, either within or round

 the

the electrified body, since if we place either our hands or face before an excited tube of glafs, or before an infulated conductor which is electrified, we fhall perceive emanations fenfible to the touch, and if we approach nearer, we fhall feel it diftinctly, and hear a weak noife; in the dark we perceive fparks of vivid light, efpecially from angular points; we fee emitted pencils of rays, or fmall flafhes of divergent flame; it is certain, therefore, that fome fubtle matter put in motion is alone capable of making thefe impreffions upon our fenfes; and we may conclude, that every electrified body is encompaffed by fome matter in motion, which is, without doubt, the immediate caufe of all the electrical phenomena, and which we term the electric matter or fluid.

Thus far, and no farther, are we warranted in affirming, on the only evidence to be admitted in philofophy, that of experiment, fact, and obfervation. There is, however, in man, a curiofity that prompts us to look beyond effects, and a difpofition that leads us to theorize, even on the moft difficult fubjects. Let us, however, do it with diffidence and caution. What then is this electric matter? or whence does it derive its origin? It apparently proceeds not from the electrified body, for that fuffers no fenfible diminution. It depends not on any property inherent in the air of the atmofphere, for three obvious reafons; firft, that electrical phenomena may be produced in a fpace from which the air has been moft carefully exhaufted. Secondly, ly, Becaufe the electrical matter has qualities which are not inherent in air; it penetrates certain bodies impervious to air, fuch as metals; it has a fenfible odour; it appears itfelf inflamed; it is capable of inflaming other bodies, and of melting metals; effects which air cannot produce. Thirdly, It tranfmits its motions with confiderably more rapidity than that of found, which is a motion of the air the moft rapid that we are acquainted with.

It is generally agreed, that the electric matter has a ftrong analogy with the matter of heat and light. It appears indeed, that nature, who is fo very œconomical in the production of principles, whilft fhe multiplies their properties fo liberally, has in no cafe eftablifhed two caufes for one effect. We may apply this remark to the electric matter; and the more we inquire into the properties of the electric matter, and thofe of the matter of heat and light, the more fhall we difcover of this analogy between them, and the more probable will it appear, that fire, light, and electricity depend upon the fame principle, and that they are only three different effects from the fame matter or effence.

1ft. Of all the means neceffary to excite the matter of heat, there is none more efficacious than that which is moft neceffary to produce electricity, namely, friction. 2dly. As fire, or caloric, extends itfelf with more facility in metals and humid bodies than in any other fpecies of bodies, fo metals and water are conductors of electricity in the fame manner as they are of heat, and, in general, the fame

 conductors

conductors are found equally good for both. 3dly. Fire, or caloric, is the moft elaftic of all bodies, and is confidered by moft philofophers as the principal caufe of that repulfion which takes place between the particles of bodies, of which the ftrongeft inftance has already been given in explaining the caufe of fluidity; and to a fimilar caufe the electric repulfion may be referred. 4thly. The pulfe and perfpiration of animals are increafed by electricity as by the actual application of heat, and the growth of vegetables is promoted by it *. 5thly. Actual ignition is produced by the electric fluid: thus it is a common experiment to fire fpirit of wine by the electric fpark; inflammable air is fet on fire by the fame means in the common electrical piftol; and even gunpowder may be exploded by a fpark from a powerful conductor. 6thly. Metals are melted by electricity, and moft inflammable fubftances are affected by it as by common fire, but in a weaker degree.† 7thly. The light emitted by the

* Sir Benj. Thomfon's experiments, Phil. Tranf. vol. lxxvi.

† Mr. Kinnerfley made a large cafe of bottles explode at once through a fine iron wire; the wire at firft appeared red hot, and then fell into drops, which burned themfelves into the table and floor, and cooled in a fpherical form like fmall fhot. Artificial lightning, from a cafe of about thirty-five bottles, will entirely deftroy brafs wire of one part in three hundred and thirty of an inch. Metals may alfo be revived by the electric fhock; and Sig. Beccaria melted borax and glafs by it. Prieftley's Hift. Elect. vi. 341—343. Seeds of clubmofs (lycopodium) were fired by it; alfo aurum fulminans, ib. 343.

electrical

electrical apparatus has all the properties of that which is emitted from the ſun, the compoſition differing in ſome reſpects, according to circumſtances, as to the predominancy of certain rays, the light in different inſtances inclining to blue, red, white, &c. according to its intenſity. 8thly. The motion of light is exceedingly rapid, whether it is reflected or refracted; in the ſame manner the electric fluid is found to move with almoſt infinite velocity, for it has been proved by experiments, that a cord twelve hundred feet long has become inſtantly electric in its whole extent *. The Abbé Nollet has communicated the electric ſhock to two hundred perſons at the ſame time, or at the leaſt perceptible inſtant.

Notwithſtanding theſe conſiderations, it muſt be confeſſed that there are ſome facts which ſeem to indicate that the electric fluid is not purely and ſimply the matter of heat or light unmixed with other ſubſtances; for 1ſt, we have obſerved, that the electric matter has the property of affecting the organs of ſcent, which belongs neither to light nor heat.

2dly. It is well known alſo, that an accumulation of the matter of fire or heat increaſes the fluidity of all bodies, and prevents them from congealing, whereas congealed fluids may be highly charged with electricity; nor does it appear to have the ſmalleſt effect in increaſing their fluidity.

* Memoires de l'Acad. des Sci. 1733, p. 247.

3d. Heat

3dly. Heat ſpreads in every direction, whereas the electrical fluid may be arreſted in its progreſs by certain bodies, which, on that account, have obtained the name of non-conductors. The Torricellian vacuum, on the contrary, affords a ready paſſage to the electric fluid, but is a bad conductor of heat *.

4thly. Whenever the matter of heat penetrates bodies, it warms as well as expands them. The electric fluid does not produce theſe effects; bodies, however long they may be electrified, become neither hotter to the touch, nor more extended in dimenſions.

5thly. The ſingular property of adhering to certain conductors, without diffuſing itſelf to others, which may be even in contact with them, ſo obſervable in the electrical fluid, is a property not common to caloric, or elementary fire. Thus we have ſeen that ſpirits were fired by an electric ſpark drawn by a wire through the water of the Thames, and large pieces of iron wire have been heated red hot, while immerſed in water, by an electrical exploſion †.

6thly. With reſpect to the identity of light and electricity, it ſhould alſo be recollected, that light pervades glaſs with the greateſt facility, whereas that ſubſtance is penetrated by the electrical fluid only in certain circumſtances, and with the utmoſt difficulty; if, therefore, it ſhould be admitted that the

* Sir Benj. Thomſon's experiments above quoted.

† Ibid.

baſis

basis of the electric matter is radically the same with the matter of heat or light, it must also be admitted, that it retains some other matter in combination with it, of the nature of which we are as yet uninformed; and it is probably this combination of foreign matter which disables it, in ordinary cases, from penetrating glass. Let it, however, be carefully remembered, that all this is speculation and conjecture, and that we at present know nothing of a certainty concerning the electrical fluid, but some of its effects.

Electrical phenomena are produced by friction, and by communication. In general, bodies which electrify the best by friction electrify the worst by communication (except glass in certain circumstances) and on the contrary, substances which electrify the best by communication electrify the worst by friction. I shall begin with those experiments which gave rise to the principal technical terms made use of in this science.

If a dry glass tube is rubbed with a piece of dry silk, and light bodies, as feathers, pith balls, &c. are presented to it, they will be first attracted, and then repelled. The best rubber for a smooth glass tube is a piece of black or oiled silk, on which a little amalgam has been placed; sealing wax, rubbed with new and soft flannel, will produce the same effect. By this friction an agent or power is put in action, and this power is called the electrical fluid; a certain quantity of this fluid is supposed to exist latent in all bodies,

bodies, in which ſtate it makes no impreſſion on our ſenſes, but when by the powers of nature or of art, this equilibrium is deſtroyed, and the agency of the fluid is rendered perceptible to the ſenſes, then thoſe effects are produced which are termed electrical, and the body is ſaid to be electrified.

If a homogenous body is preſented to the excited tube, ſo as to receive electricity from it, and the electricity remains at or near the end or part preſented, without being communicated to the reſt of the body, it is called a non-conductor or electric; but if, on the contrary, the electricity is communicated to every part, the body is called a conductor, or non-electric. A body is ſaid to be *inſulated* when it communicates with nothing but electrics.

A conductor cannot be electrified while it communicates with the earth, either by direct contact or by the interpoſition of other conductors, becauſe the electricity is immediately conveyed away to the earth.

A mutual attraction is exerted between a body in a ſtate of electricity and all non-electric bodies, which, if not large and heavy, will paſs rapidly through the air to the electrified body, where they remain till they have, by communication, acquired the ſame ſtate, when they will be repelled. If an uninſulated conductor is at hand, it will attract the ſmall body when electrified, and deprive it of its electricity, ſo that it will be again attracted by the electrified body, and repelled as before, and will continue to paſs and repaſs between the two, till the electric ſtate is entirely deſtroyed.

The following ſubſtances are reckoned among the principal conductors of the electric fluid:

Stony ſubſtances in general,
Lime-ſtone, marbles,
Oil of vitriol,
Allum,
Black pyrites,
Black lead in a pencil,
Charcoal,
All kinds of metals and ores,
The fluids of animal bodies,
All fluids, except air and oils.

Electric bodies, or thoſe ſubſtances which emit this fluid, are the following:

Amber, jet, ſulphur,
Glaſs, and all precious ſtones,
All reſinous compounds,
All dry animal ſubſtances, as ſilk, hair, wool, paper, &c.

M. Achard, of Berlin, has proved bv experiment, that certain circumſtances will cauſe a body to conduct electricity, which before was a non-conductor. The principal of theſe circumſtances are the degrees of heat to which the body is ſubjected. This gentleman agrees in opinion with M. Euler, that the principal difference between conductors and non-conductors conſiſts in the ſize of the pores of the conſtituent parts of the body.

It

It muſt be obſerved, that electrics and non-electrics are not ſo ſtrongly marked by nature as to be defined with preciſion; for the ſame ſubſtance has been differently claſſed by different writers; beſides, the electric properties of the ſame ſubſtance vary according to changes of circumſtances; thus a piece of green wood is a conductor, and the ſame piece, after it has been baked, becomes a non-conductor; when it is formed into charcoal it again conducts the electric matter; but when reduced to aſhes is impervious to it. Indeed, it might perhaps be generally ſaid, that every ſubſtance is in a certain degree a conductor of this fluid, though ſome conduct it with much more facility than others.

The inſtruments uſed in electricity are of five kinds; firſt, tubes of glaſs, or cylinders of ſealing wax; the ſecond conſiſt of a ſingle winch or of a multiplying wheel, by means of which, globes, cylinders, and plates of glaſs, of ſulphur, or of ſealing wax, are made to turn round; thirdly, metallic conductors, or ſubſtances charged with humidity; fourthly, electric bottles, commonly called Leyden phials; fifthly, electric batteries.

The firſt electrical machine made uſe of was a tube of glaſs, which, being electrified by friction, was then put in a ſtate to communicate electricity to other bodies. The beſt glaſs for this purpoſe is the fine white Engliſh cryſtal. The moſt convenient dimenſions for theſe tubes are about three feet of length, twelve or fifteen lines of diameter, and quite a line of thickneſs. It is of little importance whether the tube

tube is open or clofed at the extremities; yet it is neceffary that the air within fhould be in the fame ftate as that without; for this reafon the tube fhould at leaft be open at one end; but care muft be taken left dirt fhould be admitted into the infide, for that would confiderably impede its effects. If, notwithftanding thefe precautions, the tube receives either dirt or moifture, fome dry and fine fand fhould be introduced into the infide, and it fhould be afterwards cleaned out with fine dry cotton.

When it is intended to electrify a tube, it is only neceffary to take the end in one hand, and to continue to rub the tube with the other hand from one end to the other until it affords marks of its being fufficiently charged with the electric fluid. This friction may be performed with the naked hand when it is dry and clean, otherwife with a piece of brown paper, or waxed taffeta. When the tube has been rubbed in this manner, the circumambient air being dry, if light fubftances are prefented to it, they will be firft attracted towards it and immediately afterwards repelled.

The electric fluid may be excited in nearly a fimilar manner, by rubbing a ftick of fulphur or fealing wax.

Thefe tubes being but fmall, the electric fluid produced by thefe means is but feeble in its effects. We have feen that a method was contrived to turn a globe of glafs upon its axis, by means of a machine with a winch or multiplying wheel; this method

thod admitted of a larger ſurface, and the friction was performed with greater eaſe, by means of a rubber being placed cloſe to the revolving globe.

To conſtruct a machine ſufficiently large for all the purpoſes of electrical experiments, M. Briſſon directs that the wheel R O (ſee Plate XVI. Fig. 1.) ſhould be at leaſt four feet in diameter, and be turned round in a ſtrong and ſolid frame H I C D, &c. He directs further, that there ſhould be two handles M, *m*, ſo that two men may be employed at once in certain caſes, to give a ſufficient friction to the globe. to augment the effects. The globe S ought to be carried round between two ſmall poſts N, which ought to be ſo placed that they may be drawn farther from or nearer to the wheel, in order to admit the cord to be moved commodiouſly whenever it is contracted or extended. It is alſo neceſſary that one of theſe ſmall poſts ſhould be moveable, that it may be placed either nearer to or farther from the other, ſo that globes of different diameters may be placed in the machine; the cord of the wheel R O ſhould communicate immediately with the pulley P of the globe S.

When this machine is uſed for the purpoſes of electricity, the globe S ſhould be turned according to the order of the cyphers 1 2 3, and its equator rubbed with a leathern cuſhion ſtuffed with horſe hair, this may alſo be done by the hands when they are clean and dry. A bar of iron (A B, Fig. 2.) inſulated with the cords of ſilk *s*, *s*, is placed over the

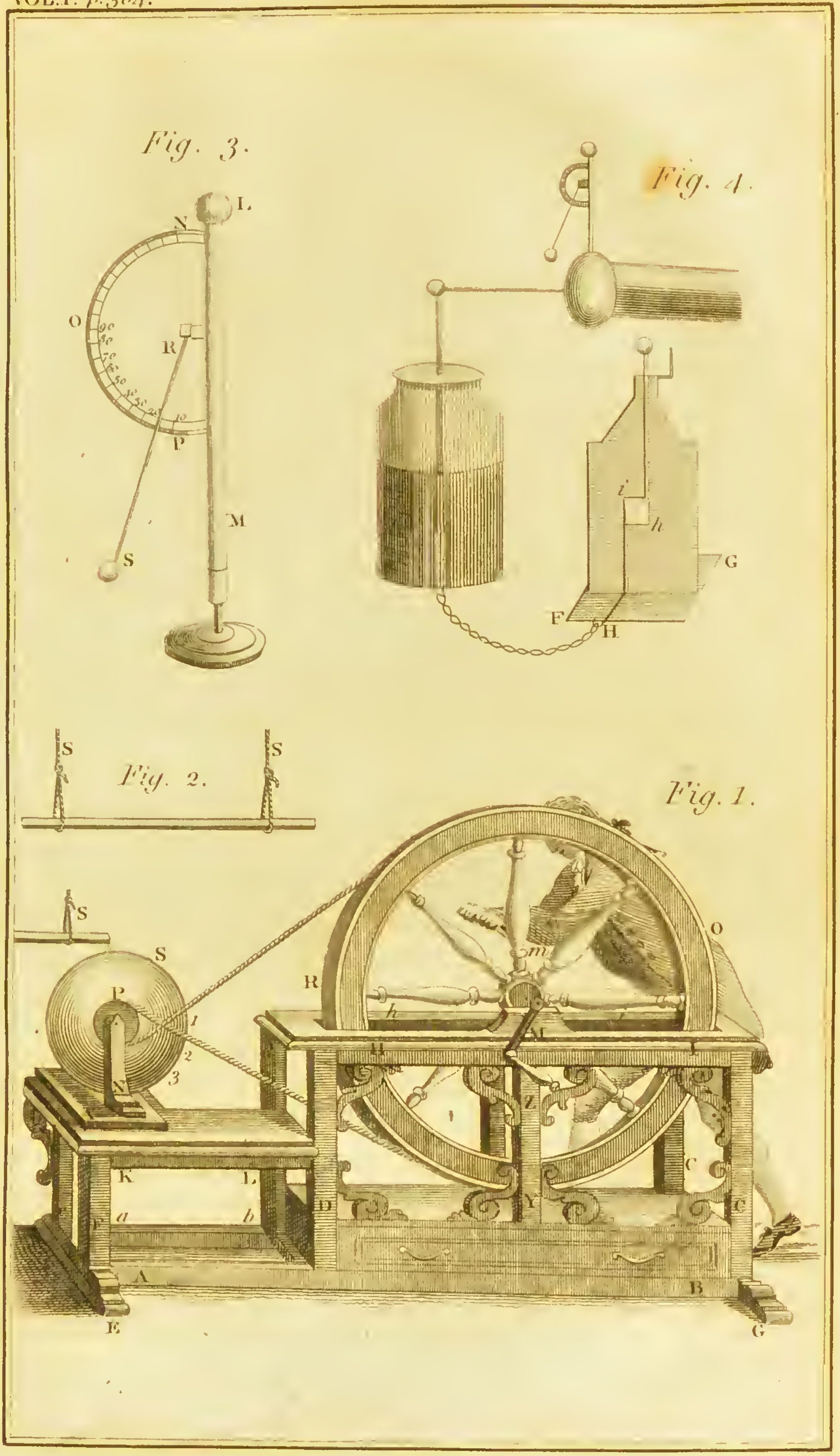

Fig. 3.
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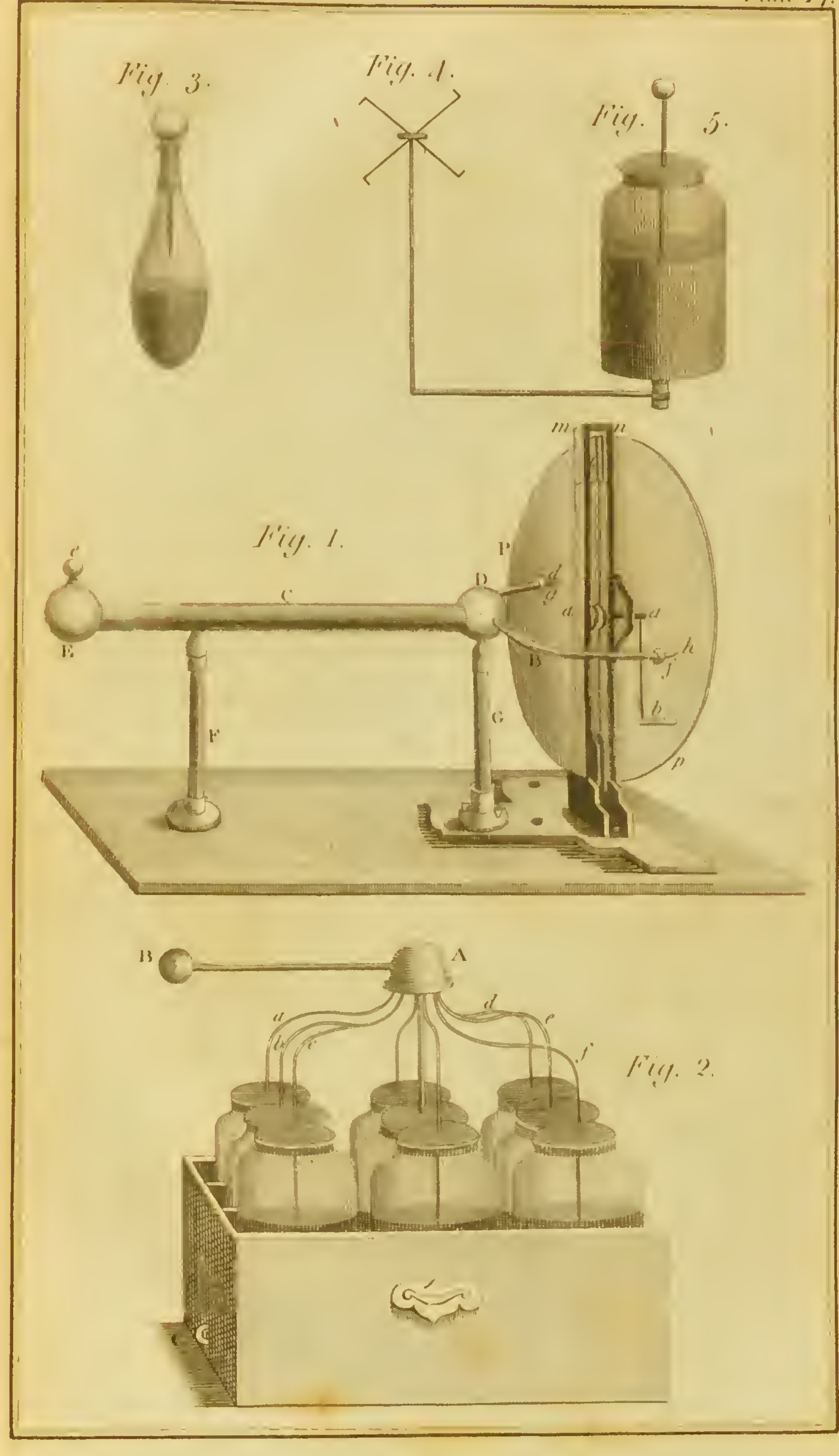
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 1.
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Fig. 2.

the globe S, this bar ſerves as a conductor to the electric fluid *.

A machine of a ſimpler conſtruction has been invented in this country, and is repreſented in Plate XVII. Fig. 1. In this inſtrument a circular plate of glaſs is employed inſtead of a globe. The plate, P *p*, is bored through the center, and mounted on an axis, *a a*, of copper or hard wood, to which is fixed the handle, *a b*. The axis is ſupported by two vertical poſts of wood, *m*, *n*, to which are appended four cuſhions, *i i*, formed according to the preceding directions, and which ſerve by their friction to excite the plate.

Before the plate a metal conductor, E D, is placed horizontally, having two arms or branches, A B, alſo of metal, each terminating in a ſmall globe or knob, which may be brought within a convenient diſtance of the place to receive the electrical fluid. The conductor itſelf is inſulated by two glaſs pillars, F G.

The advantages of this machine are, that it may be made portable, and is of ſo ſimple a conſtruction, that any gentleman in the country, after procuring a plate of a reaſonable thickneſs from a glaſs-houſe, may, by the aid of a common cabinet-maker, conſtruct one for his own uſe; the conductor may be equally inſulated by roſin, wax, ſilk, or any other electric or non-conducting ſubſtance.

* Briſſon, Traité elementaire de Phyſ. tom. iii. p. 305.

This machine is, however, feeble in its operations, compared with thofe conftructed with globes or cylinders. The moft powerful, and yet the moft fimple, of thefe that I have feen, are thofe defcribed by my late valuable friend, Mr. Adams, in his treatife of electricity.

Fig. 1. and 2, Plate XVIII. reprefent two electrical machines of the moft approved conftruction; the only difference between them is, the mechanifm by which the cylinder is put in motion.

The cylinder of the machine, Fig. 2. is turned round by two wheels, *a b*, *c d*, which act on each other by a catgut band, part of which is feen at *e* and *f*.

The cylinder in Fig. 1. is put in motion by a fimple winch, which is lefs complicated than that with a multiplying wheel (Fig. 2.): as, however, both machines are fo nearly fimilar, the fame letters of reference are ufed in defcribing them both. A B C reprefent the bottom board of the machine, D and E the two perpendicular fupports, which fuftain the glafs cylinder F G H I. The axis of the cap K paffes through the fupport D; on the extremity of this axis either a fimple winch is fixed, as in Fig. 1. or a pulley, as in Fig. 2 *. The axis

* Mr. Adams, in his Lectures on Nat. Philofophy, obferves, that machines turned by a fimple winch are lefs liable to be out of order than thofe which are turned by a multiplying wheel, and may alfo be excited more powerfully. *Adams's Lect.* vol. iv. p. 311.

of

Fig. 1.

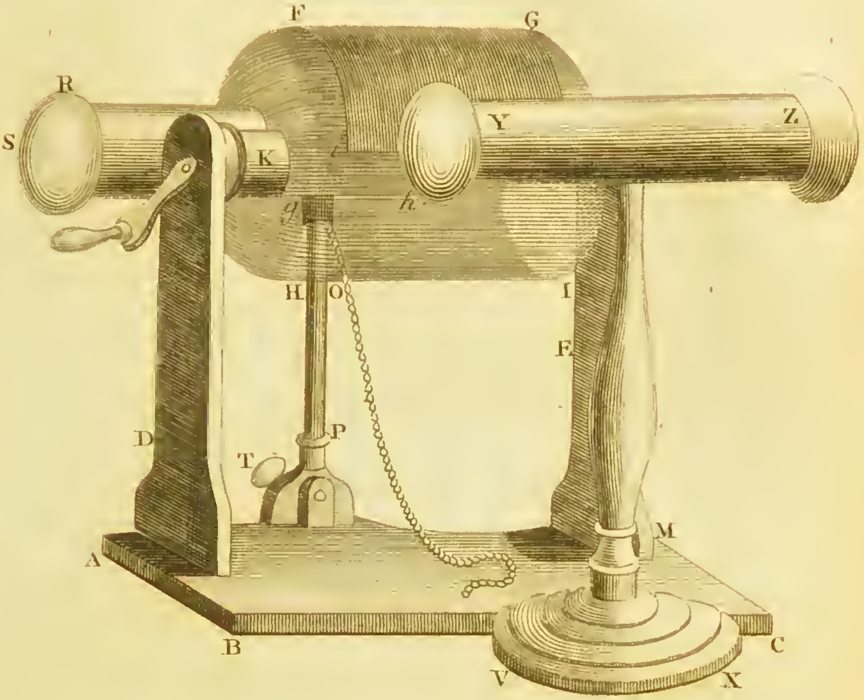
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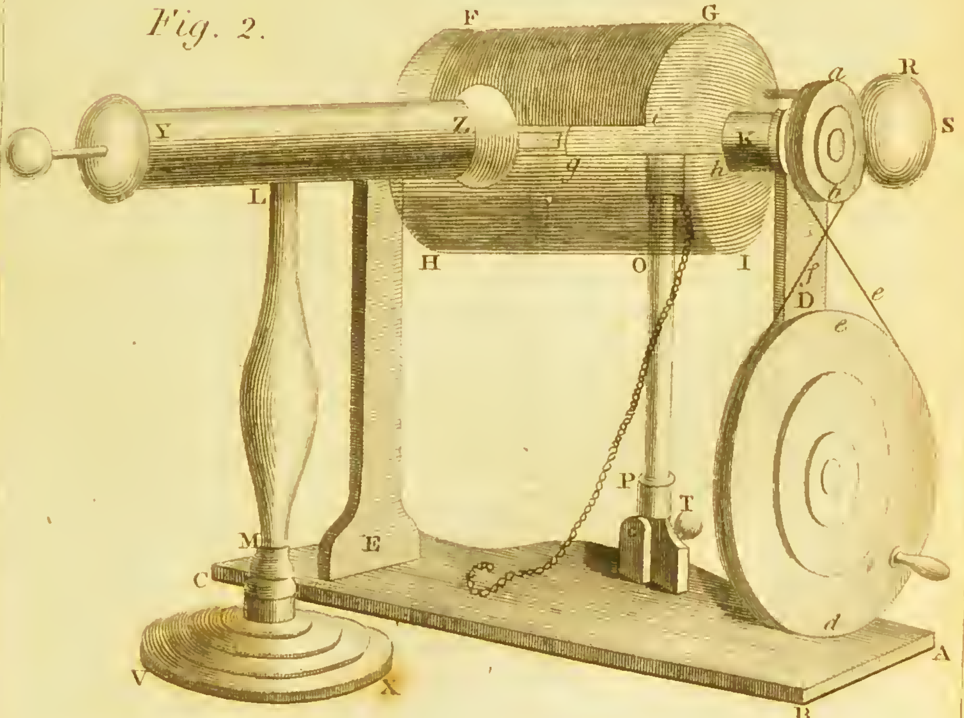
Fig. 2.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of the other cap runs in a ſmall hole, which is made in the top of the ſupporter E.

O P is the glaſs pillar to which the cuſhion is fixed; T a braſs ſcrew at the bottom of this pillar, which is to regulate the preſſure of the cuſhion againſt the cylinder. This adjuſting ſcrew is peculiarly advantageous: by it the operator is enabled to leſſen or increaſe gradually the preſſure of the cuſhion, which it effects in a much neater manner than it is poſſible to do when the inſulating pillar is fixed on a ſliding board.

On the top of the pillar O P is a conductor, which is connected with the cuſhion, and this is called the negative conductor. In both figures this conductor is ſuppoſed to be fixed cloſe to the cuſhion, and to lie parallel to the glaſs cylinder. In Fig. 1. it is brought forwards, or placed too near the handle, in order that more of it may be in ſight, as at R S; in Fig. 2. the end R S only is ſeen.

Y Z (Fig. 1. and 2.) repreſents the poſitive prime conductor, or that which takes the electric fluid immediately from the cylinder, L M the glaſs pillar by which it is ſupported and inſulated, and V X a wooden foot or baſe for the glaſs pillar. In Fig. 1. this conductor is placed in a direction parallel to the glaſs cylinder; in Fig. 2. it ſtands at right angles to the cylinder: it may be placed in either poſition occaſionally, as is moſt convenient to the operator.

Previous to relating ſeveral circumſtances, by which a large quantity of the electric fluid may be excited, it may be neceſſary to premiſe, that the reſiſtance of the air ſeems to be leſſened, or a kind of vacuum is produced, where the cuſhion is in cloſe contact with the cylinder; and that the electric matter, agreeably to the law obſerved by all other elaſtic fluids, is preſſed towards that part where it finds leaſt reſiſtance; the ſame inſtant, therefore, that the cylinder is ſeparated from the cuſhion, the fire iſſues forth in abundance, becauſe the reſiſtance made to it by the action of the atmoſphere is leſſened at that part: the effect which ariſes from the deſtruction of the attraction or coheſion between the cylinder and the cuſhion is a further proof of the truth of this hypotheſis. The more perfect the continuity is made, and the quicker the ſolution of it, the greater is the quantity which will proceed from the cuſhion.

To excite, therefore, an electrical machine effectually, we muſt firſt find out thoſe parts of the cuſhion which are preſſed by the glaſs cylinder, then the amalgam muſt be applied to thoſe parts only. The line of contact between the cylinder and cuſhion muſt be made as perfect as poſſible, and the fire which is collected muſt be prevented from eſcaping. The breadth of the cuſhion ſhould not be great, and it ſhould be placed in ſuch a manner that it may be eaſily raiſed or lowered.

In order to find the line of contact between the cylinder and cuſhion, place a line of whiting, which has been diſſolved in ſpirits of wine, on the cylinder; on turning this round, the whiting is depoſited

† on

on the cuſhion, and marks thoſe parts of it which bear or rub againſt the cylinder. The amalgam is to be put on thoſe parts only which are thus marked by the whiting.

Whenever the electricity of the cylinder grows leſs powerful, it is eaſily renewed by turning back the ſilk which lies over it, and then rubbing the cylinder with the amalgamated leather, or by altering the preſſure of the adjuſting ſcrew.

A ſmall quantity of tallow placed over the amalgam is obſerved to give more force to the electric powers of the cylinder; or the ſame end may be effected by rubbing the cylinder with a coarſe cloth, which has been a little greaſed, and afterwards wiping the ſame with a clean cloth.

As air not only reſiſts the emiſſion of the electric fluid, but alſo diſſipates what is collected, on account of the conducting ſubſtances which are floating in it, a piece of black or oiled ſilk ſhould be placed from the line of contact to the collecting points of the prime conductor, and theſe points ſhould be placed within its atmoſphere.

Sometimes the ſilk will adhere ſo ſtrongly to the cylinder, when zinc amalgam is uſed, as to render it very difficult to turn; this may be obviated by rubbing a ſmall quantity of aurum muſivum, or a little whiting, over the ſilk, when it is wiped clean *.

There

* The following directions of Mr. Adams, relative to exciting the machine, will be uſeful to the experimentaliſt:

' To excite your machine, clean the cylinder, and wipe the ſilk,

' Greaſe

CHAP. III.

OF THE VITREOUS AND RESINOUS, OR POSITIVE AND NEGATIVE ELECTRICITY.

Diſtinction in the attractive Powers of certain Electrics.—Theſe Effects found to depend not on the Nature of the Subſtance, but the Roughneſs or Smoothneſs of the Surface.—Theory of Two diſtinct Fluids.—Franklin's Theory.—Difficulties attending it.

IN a very early ſtage of the ſcience, we have ſeen, that a diſtinction was obſerved with reſpect to the attractive and repulſive powers of certain electric bodies. Thus if we electrify with the ſame ſubſtance, for inſtance, either with excited glaſs or with ſealing wax, two cork balls in an inſulated ſtate, that is, ſuſpended by ſilk lines about ſix inches long, the balls will ſeparate and repel each other; but if we electrify one of the balls with glaſs, and the other with ſealing wax, they will be mutually attracted. This circumſtance gave riſe to the opinion, that two different ſpecies of electricity exiſted, and the one was termed the *vitreous* electricity, or that produced from glaſs; and the other, which was produced from ſealing wax, reſinous ſubſtances, and ſulphur, was termed the *reſinous* electricity.

Subſequent

Subſequent experiments ſerved to ſhew, that in the common electrical machine, the rubber exhibited the appearances of the reſinous electricity, and the cylinder, that of the vitreous, while the former was connected with the earth. A divergent cone or bruſh of electrical light was obſerved to be the obvious mark of the vitreous electricity, and a ſingle globular maſs of light diſtinguiſhed the reſinous kind. The hand or body alſo, which approached the vitreous or glaſſy ſubſtance, when excited, appeared to receive the matter from the electric; but when one of the reſinous kind was excited, the electrical matter appeared to proceed from the hand or other approaching body.

Notwithſtanding, however, the names by which theſe different forms of electricity were diſtinguiſhed, as the vitreous and reſinous, it was at length diſcovered, that the different phenomena depended rather upon the ſurface, than upon the nature and compoſition of the electric; for a glaſs tube, when the poliſhed ſurface was deſtroyed, by being ground with emery, and being rubbed with a ſmooth body, exhibited all the proofs of the reſinous electricity, as much as ſulphur or ſealing wax; yet afterwards, when it was greaſed and rubbed with a rough ſurface, it reſumed its former property. It ſeems, therefore, to be a rule, that the ſmootheſt of two bodies, upon friction, exhibits the phenomena of the vitreous electricity, for baked wooden cylinders with a ſmooth rubber are reſinouſly electrified, but with a rubber of coarſe flannel exhibit the appear-

ances

ances of the vitreous kind; and even poliſhed glaſs will produce the phenomena of the reſinous electricity, if rubbed with the ſmooth hair of a cat's ſkin.

Amidſt this embarraſſing variety of experiments, thoſe philoſophers who applied to this branch of ſcience, were eagerly employed in inventing theories to account for theſe phenomena, and electricians are ſtill divided with reſpect to the cauſe.

The old theory of vitreous and reſinous electricity, or two diſtinct, poſitive, and active powers, which equally and ſtrongly attract and condenſe each other, has ſtill its ſupporters; among the ableſt of its defenders was my late friend Mr. Adams, who, it muſt be confeſſed, upon this theory, has ingeniouſly accounted for the moſt remarkable electrical phenomena *.

The theory of Franklin, however, though not without its defects, has more ſimplicity, and accounts for facts in a more eaſy and more natural manner. The principles of this diſtinguiſhed philoſopher may be reſolved into the following axioms:

1ſt. The electric matter is one and the ſame in all bodies, and is not of two diſtinct kinds.

2d. All terreſtrial bodies contain a quantity of this matter.

3d. The electric matter violently repels itſelf, but attracts all other matter.

* See Mr. Adams's Lectures on Nat. Phil. vol. iv.

4th.

4th. Glaſs and other ſubſtances, denominated electrics, contain a large portion of this matter, but are impermeable by it.

5th. Conducting ſubſtances are permeable by it, and do not conduct it merely over their ſurface.

6th. A body may contain a ſuperfluous quantity of the electrical fluid, when it is ſaid, according to this theory, to be in a *poſitive* ſtate, or electrified *plus*; and when it contains leſs than its proper ſhare it is ſaid to be *negative*, or electrified *minus*.

7th. By exciting an electric, the equilibrium of the fluid is broken, and the one body becomes overloaded with electrity, while the other is deprived of its natural ſhare.

Thus, according to the Franklinean theory, that electricity, which was before called vitreous, is now called *poſitive* electricity; and that which was termed the *reſinous*, is now denominated *negative* electricity.

It is evident, that it is only in paſſing from one body to another, that the effects of the electrical fluid are apparent. When all the adjacent bodies therefore are equally charged with electricity, no effects whatever will appear. The equilibrium muſt, according to the principles of Dr. Franklin, be deſtroyed, that is, the fluid muſt be made rarer in ſome one part, before any of the phenomena will be exhibited. In that caſe the denſe fluid ruſhing in to ſupply the deficiency in that part where it is rarer, produces the flaſh of light, the crackling noiſe, and the other effects of electricity.

The

The different effects on rough and ſmooth bodies, when excited, have been previouſly noticed. The Franklinean theory is, if a rough and ſmooth body are rubbed together, the ſmooth body will generally be electrified *plus*, and that with a rough uneven ſurface, *minus*. Thus, in the ordinary operation of the common machine, the cylinder is poſitively electrified, or plus, and the rubber negative, or minus. The redundance of the poſitive electricity is ſent from the cylinder to the prime conductor, and may be communicated from it to any conducting body. If, however, the prime conductor is made to communicate with the earth, which has a great attraction for the electrical matter (and which, being one great maſs of conducting ſubſtances, will not permit the accumulation of the fluid in a particular part) and if at the ſame time the rubber is in an inſulated ſtate, ſupported for inſtance by glaſs or any electric, theſe effects will be reverſed, for the prime conductor will then be negatively electrified, and the rubber will be plus or poſitive.

This theory is, it muſt be confeſſed, not without its difficulties, and it is much to be feared, that we have as yet no complete theory of electricity. The fact moſt difficult to be explained on the Franklinean ſyſtem is, that of two bodies negatively electrified repelling each other, for if the repulſion in the caſe of poſitive electricity is cauſed entirely, as there is reaſon to believe it is, by the electric matter, how ſhould a deficiency of that matter produce the ſame effect? Attempts have been made to explain the fact by having recourſe to the electricity of the air, which (when not charged with moiſture) is certainly an electric or non-conducting ſubſtance, and in all caſes is an imperfect electric. The cork balls, or other light ſubſtances, which are electrified negatively, are therefore ſuppoſed to be acted upon by the poſitive electricity of the air, which produces an effect adequate to their being poſitively electrified. This ſolution, however, is not quite ſatisfactory; though it is perhaps unphiloſophical to reject an hypotheſis, which explains ſome facts greatly to our ſatisfaction, merely becauſe it has not as yet explained every thing.

Dr. Franklin ſuppoſed that the electric fluid is collected from the earth, and this hypotheſis he ſupported by the following experiments.

Let one perſon ſtand on wax (or be inſulated) and rub a glaſs tube, and let another perſon on wax take the fire from the firſt, they will both of them (provided they do not touch each other) appear to be electrified to a perſon ſtanding on the floor; that is, he will perceive a ſpark on approaching either of them with his knuckle or finger; but if they touch each other during the excitation of the tube, neither of them will appear to be electrified. If they touch one another after exciting the tube, and draw the fire as before, there will be a ſtronger ſpark between them than was between either of them and the perſon on the floor. After ſuch a ſtrong ſpark neither of them diſcover *any electricity*.

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He accounts for these appearances by supposing the electric fluid to be a common element, of which each of the three persons has his equal share before any operation is begun with the tube.

A, who stands upon wax and rubs the tube, collects the electrical fire from himself into the glass, and his communication with the common stock being cut off by the wax, his body is not again immediately supplied.

B, who also stands upon wax, passing his knuckle along the tube, receives the fire which was collected from A, and being insulated, he retains this additional quantity.

To the third person, who stands upon the floor, both appear electrified; for he, having only the middle quantity of electrical fire, receives a spark on approaching B, who has an over quantity, but gives one to A, who has an under quantity.

If A and B approach to touch each other, the spark is stronger, because the difference between them is greater. After this touch there is no spark between either of them and C, because the electrical fluid in all is reduced to the original equality. If they touch while electrifying, the equality is never destroyed, the fire is only circulating; hence we say that B is electrified positively, A negatively *.

* Mr. Adams on Electricity, p. 43.

CHAP. IV.

THE LEYDEN PHIAL, ELECTRICAL BATTERY, AND OTHER PARTS OF THE APPARATUS.

Theory of the Leyden Phial.—Its Use in Electricity.—Description of the best Apparatus of this Kind.—The Charge resides in the Glass.—Curious Experiments with the Leyden Phial.—Electrical Battery.—Instructions relative to it.—Experiments with the electrical Battery.—Electrical Bells.—Electrophorus.—Electrometer.

IN order to underſtand properly the nature of what is called the Leyden phial, or electrical jar, it will be neceſſary to revert to what has been ſaid both in the introduction and in the preceding chapter on poſitive and negative electricity. If a piece of glaſs is coated with any conducting ſubſtance, it may be made to accumulate the electrical matter to a ſurpriſing degree. In this caſe one ſide of the glaſs, if it does not exceed a given thickneſs, will be poſitively electrified, and the other negatively. The form of the glaſs is of no conſequence in this experiment; it may be either flat, cylindrical, or otherwiſe.

The object of the philoſopher being, therefore, on many occaſions, to collect a large quantity of electricity, by means of the ſurfaces of electrics, and, as as flat plates are neither neceſſary nor convenient for this purpoſe, he accommodates himſelf with a ſufficient number of prepared jars. Theſe are made of various ſhapes and magnitudes, but the moſt uſeful are thin cylindrical glaſs veſſels, about four inches in diameter, and fourteen in height, coated within and without (except about two inches from the top) with tinfoil, or any other conducting ſubſtance.

If one ſide of this jar is electrified, while the other ſide communicates with the earth, it is ſaid to be charged.

When a communication is formed from one ſide of the jar to the other by a conducting ſubſtance, after it has been charged, an exploſion will take place, and this is called diſcharging the jar. This phial is incapable of being charged when it is inſulated; that is, when neither ſide communicates with the earth. When it is charged, the two ſides are in contrary ſtates, the one being poſitively, the other negatively electrified.

A jar is ſaid to be poſitively electrified when the inſide receives the fluid from the conductor, and the outſide is connected with the earth. It is negatively electrified when the outſide receives the fluid from the conductor, and the inſide communicates with the earth; but it is neceſſary that the jar charging negatively ſhould be inſulated, becauſe the fluid is, in the firſt inſtance, conveyed to the coating, and would be immediately carried to the earth if it was not inſulated.

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The moſt uſual forms of the Leyden phial are repreſented in Fig. 3. and 5. Plate XVII. and its nature may be exemplified by the following experiment:

Place the phial (Fig. 5.) on an inſulated ſtand; bring the coating in contact with the conductor; turn the machine ſlowly, and after a few turns remove the phial from the conductor; then form a communication between the outſide and the inſide of the phial, by placing one end of the diſcharging rod firſt upon the coating, and then bringing the other end of the rod to the braſs ball of the bottle; in this caſe there will be no exploſion, becauſe, both ſides being inſulated, the bottle was not charged; but if a chain is ſuſpended from the braſs ball of the phial to the table, and the coating brought in contact with the conductor, after a few turns of the machine remove the phial as before; then if the diſcharger is applied, an exploſion will be heard, and the bottle will be diſcharged; becauſe, in this caſe, the inſulation of the inſide is deſtroyed by the chain, and the phial becomes capable of receiving a charge.

That the charge of a coated jar reſides in the glaſs, and not in the coating, is proved in the following manner: place a plate of glaſs between two metallic plates, about two inches in diameter, ſmaller than the plate of glaſs; charge the plate of glaſs, and then remove the upper metallic plate by an inſulated handle; take up the glaſs plate, and place it between two other plates of metal unelectrified and insulated, and the plate of glass thus coated afresh will still be charged. The following experiments are further illustrative of the nature of the Leyden phial.

A cork ball, or an artificial spider made of burnt cork, with legs of linen thread, suspended by silk, will play between the knobs of two bottles, one of which is charged positively, the other negatively, and will in a little time discharge them.

A ball suspended on silk, and placed between two brass balls, one proceeding from the outside, the other from the inside of a Leyden jar, when the bottle is charged, will fly from one knob to the other, and by thus conveying the fire from the inside to the outside of the bottle will soon discharge it.

An insulated cork ball, after having received a spark, will not play between, but be equally repelled by two bottles, which are charged with the same power.

A wire is sometimes fixed to the under part of the insulated coated phial (Fig. 5.) and *b c* is another wire fitted to, and at right angles with the former; a brass fly (Fig. 4.) is placed on the point of this wire; charge the bottle, and all the time the bottle is charging the fly will turn round; when it is charged the needle will stop. If the top of the bottle is touched with the finger, or any other conducting substance, the fly will turn again till the bottle is discharged. The fly will electrify a pair of balls positively while the bottle is is charging, and negatively, when it is difcharging *.

When a Leyden phial pofitively charged is infulated, it will give a fpark from its knob to an excited ftick of wax, but not a fpark will pafs at that time between it and an excited glafs tube.

An additional quantity of the fluid may be thrown on one fide of the jar, if by any contrivance an equal quantity may be made to efcape from the other, and not otherwife.

Electricians, in order to increafe the force of the electric explofion, connect feveral Leyden phials together in a box; and this collection they call an electrical battery.

In this apparatus the bottom of the box (Plate XVII. Fig. 2.) is covered with tin-foil, to connect the exterior coatings; the infide coatings of the jars are connected by the wires *a*, *b*, *c*, *d*, *e*, *f*, which meet in the large ball A; C is a hook at the bottom of the box, by which any fubftance may be connected with the outfide coating of the jars; a ball, B, proceeds from the infide, by which the circuit may be conveniently completed. Mr. Adams gives the following precautions to thofe who make ufe of an electrical battery †.

The top and uncoated part of the jar fhould be kept dry and free from duft; and after the explofion has taken place, a wire from the hook is to be connected to the ball, and left there till the bat-

* Mr. Adams's Effay on Elect. p. 131. † Ibid. p. 147.

tery is to be charged again, by which means the inconveniences arising from the frequent residuum of a charge will be obviated.

Every broken jar in a battery must be taken away, before it is possible to charge the rest.

It has been recommended, not to discharge a battery through a good conductor, if the circuit is not at least five feet long; but it must be observed, that in proportion to the lengthening of the circuit the force of the shock will be lessened.

Jars made of the green glass, manufactured at Newcastle, are said to endure an explosion without a probability of breaking.

If the spark from the explosion is concentrated, by causing it to pass through small circuits of non-conducting substances, the force of the battery will be considerably increased. For this purpose, cause the spark to pass through a hole in a plate of glass one twelfth or one-sixth of an inch diameter, by which means it will be more compact and powerful. By wetting the part round the hole, the spark, by converting this into vapour, may be conveyed to a greater distance, with an increase of rapidity, attended with a louder noise than common. Mr. Morgan, by attending to these and some other circumstances, has melted wires, &c. by the means of small bottles.

If the charge of a strong battery is passed through two or three inches of small wire, the latter will sometimes appear red hot, first at the positive side; and the redness will proceed towards the other end.

If

If a battery is difcharged through a fmall fteel needle, it will, if the charge is ftrong, communicate magnetifm to the needle.

If the difcharge of a battery paffes through a fmall magnetic needle, it will deftroy the polarity of the needle, and fometimes invert the poles; but it is often neceffary to repeat this feveral times.

Dr. Prieftley could melt nine inches of fmall iron wire at the diftance of fifteen feet, but at the diftance of twenty feet he could only make fix inches of it red hot, fo that we may infer from this, that notwithftanding their conducting power, ftill metals refift in fome degree the paffage of the electric fluid, and therefore in eftimating the conducting powers of different fubftances, their length muft not be forgotten.

If a flender wire is inclofed in a glafs tube, and a battery difcharged through this wire, it will be thrown into globules of different fizes, which may be collected from the inner furface of the tube; they are often hollow, and little more than the fcoria or drofs of the metal.

Dr. Watfon and fome other gentlemen made feveral curious experiments to afcertain the diftance to which the electric fhock might be conveyed, and the velocity of its motion, which were briefly noticed in the firft chapter. In the firft experiment, the fhock was given, and fpirits fired by the electric matter which had been conveyed through the river Thames. In another experiment, the electric fluid was made to pafs through a circuit of two miles, croſſing the New River twice, going over ſeveral gravel pits and a large field, and afterwards conveyed through a circuit of four miles. This motion was ſo inſtantaneouſly performed by the electric fluid, that an obſerver, in the middle of a circuit of two miles, felt himſelf ſhocked at the ſame inſtant that he ſaw the phial diſcharged.

Notwithſtanding this ſurpriſing velocity, it is certain, however, that both ſides of a charged phial may be touched ſo quickly, even by the beſt conductors, that all the electric fluid has not time to make the circuit, and the phial will remain but half diſcharged; and there are ſeveral inſtances where the motion appears ſlow, and not eaſily reconcileable with the amazing velocity we have obſerved in the inſtance above: indeed it is certain, that this fluid is reſiſted in ſome degree in its paſſage through or over every ſubſtance.

There is another part of an electrical apparatus, originally of German invention, which, before the concluſion of that which may be called the mechanical part of electricity, it will be proper to notice. It is chiefly illuſtrative of the electrical attraction. This apparatus conſiſts of three ſmall bells, ſuſpended from a narrow plate of metal; the two outermoſt by chains, and that in the middle, from which a chain paſſes to the floor, by a ſilken ſtring. Two ſmall knobs of braſs are alſo hung, by ſilken ſtrings, on each ſide of the *bell* in the middle, which ſerve for clappers. When this apparatus is connected with an electrified conductor, the outer-

* moſt

moſt bells, ſuſpended by the chains, will be charged, attract the clappers, and be ſtruck by them. The clappers, becoming electrified likewiſe, will be repelled by theſe bells, and attracted by the middle bell, and will diſcharge themſelves upon it by means of the chain extending to the floor. After this they will be again attracted by the outermoſt bells, and thus, by ſtriking the bells alternately, occaſion a ringing, which may be continued at pleaſure. Flaſhes of light will alſo be ſeen in the dark between the bells and the clappers; and if the electricity is ſtrong, the diſcharge will be made without actual contact, and the ringing will ceaſe.

If an apparatus of this kind is joined to one of thoſe conducting rods, erected to protect buildings from the effects of lightning, it will ſerve to give notice of the approach and paſſage of an electrical cloud.

It is remarkable, that in certain caſes bodies electrified will retain their electric power for almoſt any length of time, and on this principle a very ingenious inſtrument has been conſtructed, called an electrophorus. This machine conſiſts merely of a maſs of reſinous matter, contained in a box for the convenience of carriage, and a plate of metal fitted to communicate with it, which is lifted by a handle of glaſs, or ſome non-conducting ſubſtance. The reſinous maſs being rubbed with a flannel, or even with the hand, and the plate of metal being applied to it, the metal will become charged, and give out ſparks very freely to any conducting body; and this property of communicating electricity the reſinous maſs will retain for a length of time, without any freſh application whatever.

To explain theſe phenomena it will be again neceſſary to recur to what has been ſaid concerning negative and poſitive electricity; it will be neceſſary alſo to recollect, that the negative electricity was originally termed the *reſinous*, becauſe it was at firſt thought to be peculiar to thoſe ſubſtances. In the electrophorus, therefore, the lower plate, or reſinous maſs, being negatively electrified, the matter is taken from the metal plate, and this becoming alſo negatively electrified, the fluid is attracted from any body which is preſented to it.

Several inſtruments have been invented for meaſuring the quantity of electricity contained in any body. Theſe generally are formed upon the principle of the electric attraction, and conſiſt of a ſmall pith ball, or other light body, ſuſpended on a moveable arm, with a kind of ſemi-dial to mark the degrees. Mr. Adams recommends Mr. Henley's quadrant electrometer for this purpoſe, which he deſcribes as follows: "It conſiſts (Fig. 3. Plate XVI.) of a perpendicular ſtem formed at top like a ball, and furniſhed at its lower end with a braſs ferrule and pin, by which it may be fixed in one of the holes of the conductor, as at Fig. 4. or at the top of a Leyden bottle. To the upper part of the ſtem, a graduated ivory ſemicircle is fixed,

about

about the middle of which is a braſs arm or cock, to ſupport the axis of the index. The index conſiſts of a very ſlender-ſtick, which reaches from the center of the graduated arch to the braſs ferrule; and to it's lower extremity is faſtened a ſmall pith ball nicely turned in the lathe. When this electrometer is in a perpendicular poſition, and not electrified, the index hangs parallel to the pillar; but when it is electrified, the index recedes more or leſs, according to the quantity of electricity."

Chap. V.

GENERAL EFFECTS OF ELECTRICITY.

Phenomena of Attraction and Repulsion.—Electrical Atmosphere.—Different Effects on different Substances.—Electrical Cohesion.—Experiments on Silk Stockings.—On the Evaporation of Fluids.—Vegetation.—Animal Perspiration.—Inflammation of Spirits.—Animals killed by Electricity.—Curious Phenomena in vacuo.—Recapitulation of Principles.

THE various phenomena of electricity may, for the sake of perspicuity, be divided into two classes; the first of which may be included under the general head of attraction and repulsion; and under the second may be ranged all those phenomena which are accompanied with the luminous appearances, and that effect on the animal frame which is termed the electrical shock. Though some of these may appear at first to have very little analogy with the former class, yet we shall have frequent opportunities of inferring, that they are only necessary effects from one common cause, and rather differ in their circumstances than in their nature. The atmospherical phenomena will demand a distinct chapter.

It follows, from what has been already stated, that every body electrified, whether by friction, or by communication;

communication; whether by the means of glaſs, or any reſinous ſubſtance; is ſurrounded by a kind of atmoſphere of that fluid which is called the *electrical matter*.

The proof on which this hypotheſis reſts is, that light bodies are actually lifted up, and carried to or from the electrified body, which, the ſupporters of this theory alledge, could only be effected by their being enveloped in ſome fluid medium. Thus, when the hairs on the head of a perſon electrified ſtand erect, or the fibres of a ſoft feather ſpread out, as if to meet or recede from the conductor, according to circumſtances, every particular hair or fibre is ſuppoſed to be ſurrounded with an electrical atmoſphere.

It is demonſtrated by Earl Stanhope, in his ingenious treatiſe on electricity, that the denſity of the electrical atmoſphere diminiſhes exactly in proportion to the ſquares of its diſtance from the center of the electrified body.

Thoſe attractions and repulſions, which we have ſeen take place when light bodies are brought near to electrified ſubſtances, are, agreeably to the notions of ſome philoſophers, cauſed by two currents of the electric fluid; the current which departs from the bodies brought near to the electrified ſubſtance cauſes thoſe bodies to appear to be attracted, and the current which departs from the electrified ſubſtance repels them: theſe two effects taking place in the ſame inſtant, we may infer that theſe two currents are ſimultaneous.

A body

A body repelled by an electrified ſubſtance will be attracted by this ſubſtance as ſoon as it has touched any non-electric body.

An electrified ſubſtance, if it is left free to move, is attracted by a non-electric body not electrified. Thus a ſmall thin plate of metal, electrified and ſuſpended by a thread of ſilk, is attracted either by a man's hand, a piece of green wood, or by a metal rod preſented to it.

All ſubſtances are not attracted with equal force by electrified bodies; in general thoſe, which are in their texture the denſeſt and moſt compact, are more readily attracted and repelled, and are ſubject to the influence of electricity at a greater diſtance than thoſe which are looſer and more porous in their conſiſtence. A ribband or thread, when waxed or gummed, becomes more ſubject to this attraction and repulſion than it was in its original ſtate. Of all ſubſtances, gold leaf appears the moſt eaſily affected by electrical attraction.

Electrified bodies adhere ſo cloſely together, that the circumſtance has given occaſion to a new term in philoſophy, and it has been called the *electrical cohesion.* This fact was pleaſantly illuſtrated by ſome experiments on ſilk ſtockings, communicated to the Royal Society by Mr. Robert Symner a few years ago. Two ſilk ſtockings, the one black and the other white, had been for ſome time upon one leg, and were then rubbed with the hand, and both pulled off together; it appears that in this caſe the two ſtockings will adhere together in ſuch a manner as as to require a confiderable force to feparate them. M. Briffon, who repeated the experiment, obferves, that after he had feparated the white from the black ftocking another phenomenon occurred; for while he held them, one in each hand, fufpended in the air, they fwelled and puffed up as wide as if the leg had remained in them; when they were brought within ten or twelve inches of each other, they rufhed precipitately upon one another, and adhered forcibly together; but this adhefion was not fo great as that which took place while the ftockings were one within the other. Mr. Symner fuppofed, that the fuccefs of this experiment depended upon the contraft between the black and white colour; but M. Briffon proves this hypothefis to be without foundation, having made the experiment by fubftituting for the black ftocking another of a different colour, and even a white one; but he confeffes, that when the experiment was made with two white filk ftockings the effects were weak.

Electrical attraction appears not to be equally ftrong in vacuo as in the open air. From feveral experiments of Beccaria's we learn, that if the air is thoroughly exhaufted out of a glafs receiver, the attraction and repulfion of electrified light bodies within the receiver becomes languid, and foon ceafes altogether.

Electricity augments the natural evaporation of fluids, and efpecially of thofe fluids which are moft fubject to evaporation of themfelves; and it has alfo a great effect on fluids, when the veffels contain-

ing

ing them are non-electrics. If a humid body, a ſponge for inſtance, is placed upon a conductor poſitively electrified, the evaporation will go on much more rapidly, and it will be much ſooner dry, than a ſimilar body differently circumſtanced.

Dr. Prieſtley alſo gives us reaſon to ſuppoſe, that plants, when electrified, vegetate earlier and more vigorouſly than thoſe which have not been ſubjected to this influence.

That electricity increaſes the inſenſible perſpiration of animals may be inferred from the circumſtance that electrified animals are always lighter than thoſe which are not.

The ſtream of electrical fluid has no ſenſible heat, but even appears cold to the touch; yet we have ſeen that the more inflammable bodies, and particularly ſpirit of wine, may be ignited by it. This experiment may be eaſily made by a ſpark from a common machine. Let a perſon inſulated, and communicating with a charged conductor, hold in his hand a quantity of rectified ſpirit in a metal ſpoon. If the ſpirit has been a little warmed over a candle previouſly, the experiment will be more certain to ſucceed. Let another perſon then, not inſulated, but communicating with the floor, preſent his finger to the ſpirit, a ſpark will immediately paſs between the ſpoon and the finger, and the ſpirit will be inflamed. This phenomena might paſs for an exertion of magic in an ignorant country, or an ignorant age.

By

By a ſmart ſhock of electricity from a charged phial, or a battery, ſmall animals may be killed; but I have not underſtood that human art has yet been able to conſtruct a battery large enough to kill an animal above the ſize of a ſheep or a dog. The immediate or proximate cauſe of the death of animals by electricity, or by lightning, which is natural electricity, has not yet been aſcertained. It was once ſuppoſed that the living principle was extinguiſhed by the burſting of ſome blood veſſel, from the violence of the ſhock; but a dog, which was killed by lightning, was carefully diſſected, and none of the veſſels found in the leaſt injured. Beccaria recovered ſome perſons apparently ſtruck dead by lightning; and when queſtioned with reſpect to the pain or ſuffering which they endured, they only complained of an unuſual numbneſs or wearineſs in their limbs. The fleſh of animals killed by electricity is rendered extremely tender, and is recommended by Dr. Franklin as an article of luxury. It will alſo putrify in a much ſhorter time than the fleſh of thoſe which are killed in any ordinary way.

The luminous effects of electricity are not preciſely the ſame in vacuo as in the open air; and indeed a very curious phenomenon has been produced by injecting the electric light in a vacuum.

If a wire with a round end is faſtened in an exhauſted receiver, and preſented to a conductor of an electrical machine, every ſpark will paſs through the vacuum in a broad ſtream of light, viſible the whole

whole length of the receiver, moving with regularity (unlefs it is turned back by fome non-electric) and then dividing itfelf into a variety of beautiful rivulets, which are continually feparating and uniting in a pleafing manner. When the veffel is grafped by the hand, a pulfation is perceived like that of an artery, and the fire inclines towards the hand. A fmall quantity of air is, however, neceffary to occafion the greateft luminous effect.

The following is a recapitulation of what M. Briffon confiders as fundamental principles, confirmed, he fays, by his own experiments, feconded by thofe of other philofophers *.

The electric fluid is the fame in effence with that of light and heat, but combined with a fubftance which affects the organs of fcent.

When bodies are electrified by glafs, they furnifh tufts or pencils of light; but if electrified by fulphur or refinous fubftances, they only produce points or fparks of light; bodies prefented to thofe electrified by glafs produce only luminous points, while thofe which are prefented to bodies which are electrified by fulphur produce beautiful pencils or tufts of light.

To electrify bodies by communication, it is neceffary to infulate them; the fubftances the moft proper for this purpofe are thofe which electrify the beft by friction.

Glafs, though it electrifies very well by friction, electrifies alfo by communication, even without any

* Traité Element. de Phyf. Tom. iii. p. 435.

preliminary

preliminary preparation; yet it is very proper to insulate.

Electrical phenomena are not produced entirely from the bodies upon which the electrifying machine acts; the adjacent bodies or substances contribute towards their production.

The energy of the electric virtue is augmented, in conductors, more by an increase of surface, than by an augmentation of the mass.

Electrified bodies adhere one to another, so that they cannot be separated without a considerable effort, as was exemplified in the case of two silk stockings of various colours.

Electricity accelerates the evaporation of liquors, and the perspiration of animals.

The pencils or tufts of light, which are seen at the extremities or angles of electrified bodies, are always composed of divergent rays when they pass in the air; but if a *non-electric* or conducting body is presented to them, they lose a great deal of their divergency; their rays sometimes become even convergent, in order that they may approach towards that body which is more permeable than the air; and if they are made to pass into a vacuum, they will assume the form of a large branch of light nearly cylindrical, or in the form of a spindle.

The spark which shines between two bodies is capable of setting combustible matters on fire.

Chap. VI.

OF THUNDER AND LIGHTNING, METEORS, WATER-SPOUTS, &c.

Theory of Lightning.—Description of a Thunder Storm.—Observations relative to the Electricity of the Atmosphere.—Melting of Metals by the Cold Fusion a vulgar Error.—Conductors of Lightning.—How to be safe in a Thunder Storm.—Application of Electricity to other atmospherical Phenomena.—Rain.—Hail.—Snow.—Meteors.—Water-spouts.

IT no longer remains a doubt among philosophers, that the cause which produces the effects of thunder is the same with that which produces the ordinary phenomena of electricity; the resemblance between them is indeed so great, that we cannot believe thunder itself to be any other than a grander species of electricity, naturally excited without the feeble efforts of human art. This fluid, probably, is diffused through the whole atmosphere at all times, either in a smaller or greater degree, and is occasionally perceptible to our senses, according to the concurrence of natural circumstances.

The cloud which produces the thunder and lightning may be considered as a great electrified body; but how has the cloud acquired its electric virtue? is the rational request of an inquisitive mind: and to satisfy this enquiry it will be necessary

ſary to refer to what has been before obſerved, that this power is produced in bodies in two modes, by friction, and by communication. Bodies electrified by friction communicate their virtue to other bodies which are ſuſceptible of it, being inſulated, and at a convenient diſtance. As air, therefore, is an idio-electric body, it is not unphiloſophical to ſuppoſe, that in ſtormy weather eſpecially, when it is common to obſerve the clouds and the wind take contrary courſes, a part of the atmoſphere, ruſhing by the other, may cauſe the air to be electrified by the friction of its own particles, or by rubbing againſt terreſtrial objects which it meets in its paſſage, or perhaps againſt the clouds themſelves. It is probable alſo, that the inflammable ſubſtances, which ariſe and accumulate in the cloudy regions, contribute to increaſe the effects, not only of themſelves, but, perhaps, ſtill more, by the electric matter which they carry along with them. Another circumſtance, which further inclines me to make this inference is, that thunder ſtorms are more frequent and tremendous in thoſe times and places, when and where we have reaſon to conclude that theſe exhalations are in the greateſt abundance in the atmoſphere, as in warm ſeaſons and climates, as well as in thoſe places where the earth is filled with ſubſtances capable of furniſhing a large quantity of theſe exhalations, and in particular in the neighbourhood of volcanoes.

A cloud in a thunder ſtorm may be conſidered as a great conductor, actually inſulated and electrified;

trified; and it may be fuppofed to have the fame effect upon thofe non-electrics which it meets with in its courfe, as our common conductors have upon thofe which are prefented to them. If a cloud of this kind meets with another which is not electrified, or lefs fo than itfelf, the electric matter flies off from all parts towards this cloud; hence proceed flafhes of lightning, and the formidable report of thunder.

'Thunder ftorms,' fays Beccaria, 'generally happen when there is little or no wind, and their firft appearance is marked by one denfe cloud, or more, increafing very faft in fize, and rifing into the higher regions of the air; the lower furface black, and nearly level, but the upper finely arched, and well defined. Many of thefe clouds feem frequently piled one upon another, all arched in the fame manner; but they keep continually uniting, fwelling, and extending their arches.

'At the time of the rifing of this cloud, the atmofphere is generally full of a great number of feparate clouds, motionlefs, and of odd and whimfical fhapes. All thefe, upon the appearance of the thunder cloud, draw towards it, and become more uniform in their fhapes as they approach, till coming very near the thunder cloud, their limbs mutually ftretch towards one another; they immediately coalefce, and together make one uniform mafs. But fometimes the thunder cloud will fwell, and increafe very faft, without the conjunction of any of thefe adfcititious clouds, the vapours of the atmofphere forming themfelves into clouds where-ever it paſſes. Some of the adſcititious clouds appear like white fringes at the ſkirts of the thunder cloud, but theſe keep continually growing darker and darker as they approach or unite with it.

'When the thunder cloud is grown to a great ſize, its lower ſurface is often ragged, particular parts being detached towards the earth, but ſtill connected with the reſt. Sometimes the lower ſurface ſwells into various large protuberances, bending uniformly towards the earth. When the eye is under the thunder cloud, after it is grown larger, and well formed, it is ſeen to ſink lower, and to darken prodigiouſly, at the ſame time that a number of ſmall adſcititious clouds (the origin of which can never be perceived) are ſeen in a rapid motion, driving about in very uncertain directions under it. While theſe clouds are agitated with the moſt rapid motions, the rain generally falls in the greateſt plenty, and if the agitation is exceedingly great, it commonly hails.

'While the thunder cloud is ſwelling, and extending its branches over a large tract of country, the lightning is ſeen to dart from one part of it to another, and often to illuminate its whole maſs. When the cloud has acquired a ſufficient extent, the lightning ſtrikes, between the cloud and the earth, in two oppoſite places, the path of the lightning lying through the whole body of the cloud and its branches. The longer this lightning continues, the rarer the cloud grows, and the leſs dark is its appearance, till at length it breaks in different places, and difplays a clear fky.'

It is the opinion of the fame author, that the clouds ferve as conductors to convey the electric fluid from thofe places of the earth which are overloaded with it, to thofe which are exhaufted of it.

To prove that the earth is often pofitively charged with refpect to the clouds in one part while it is negative in another, he adverts to the fall of great quantities of fand, and other light fubftances, which are often carried into the air, and fcattered uniformly over a large tract of country, when there was no wind to effect this phenomenon, and even when there was, they have been carried againft the wind; he therefore fuppofes, that thefe light bodies are raifed by a large quantity of electrical matter iffuing out of the earth.

This comparatively rare phenomenon, he thinks, exhibits both a perfect image and demonftration of the manner in which the vapours of the atmofphere are raifed to form thunder clouds. The fame electric matter, wherever it iffues, attracts to it, and carries into the higher regions of the air, the watery particles difperfed in the atmofphere. The electric matter afcends, being folicited by the lefs refiftance it finds there than in the common mafs of the earth, which at thofe times is generally very dry, and confequently highly electric. The uniformity with which thunder clouds fpread themfelves, and fwell into arches, muft be owing to their being affected by fome ſome cauſe, which, like the electric matter, diffuſes itſelf uniformly wherever it acts, and to the reſiſtance they meet with in aſcending through the air.

The ſame cauſe, which firſt raiſed a cloud from vapours diſperſed in the atmoſphere, draws to it thoſe already formed, and continues to form new ones, till the whole collected maſs extends ſo far as to reach a part of the earth where there is a deficiency of electric fluid; thither alſo they will be attracted, and thus the maſs ſerves as a conductor. When the clouds are attracted in their paſſage by thoſe parts of the earth, where there is a deficiency of the fluid, thoſe detached fragments are formed, and alſo thoſe uniform depending protuberances, which are probably the cauſe of water-ſpouts.

A wind always blows from the place whence a thunder cloud proceeds, and the wind is more or leſs violent in proportion to the ſudden appearance of the thunder cloud, the rapidity of its expanſion, and the velocity with which the adſcititious clouds join it. The ſudden condenſation of ſuch a prodigious quantity of vapour muſt diſplace the air, and agitate it on all ſides.

In three ſtates of the air, ſays the author above quoted, I could find no electricity in it. 1ſt. in windy weather. 2d. When the ſky was covered with diſtinct and black clouds, which had a ſlow motion. 3d. In moiſt weather not actually raining.

In rainy weather, without lightning, his apparatus was always electrified a little time before the rain

 fell,

fell, and during the time of rain, but ceafed a little before the rain was over.

The higher his rods reached, or his kites flew, the ftronger figns they gave of being electrified.

The clouds are fometimes pofitively, and fometimes negatively electrified. In the latter cafe the lightning is fuppofed, upon the Franklinian theory, to proceed from the earth to the cloud. The general effects of lightning are precifely the fame with thofe of the electric fhock, only greatly magnified. It may not be improper in this place to notice an old error, namely, the *melting* of *metals* by lightning, by what has been called the *cold fusion*. The error is found to reft upon certain ill attefted relations of fwords being melted in the fcabbard by lightning, and money in the bag, without injuring the fcabbard, or the bag. A variety of experiments have been accurately made to determine the fact; the refults of which have been, that the thin edge of the fword, or of the money, might have been inftantaneoufly melted, and yet fo inftantaneoufly cooled, as neither to affect the fcabbard nor the bag. A very fmall wire will inftantly melt and inftantly cool in the flame of a common candle.

Mr. Kinnefley inclofed a fmall wire in a goofe quill filled with loofe grains of gunpowder, which took fire as readily as if they had been touched by a red hot poker; tinder was kindled when tied to a piece of the fame wire; but no fuch effects could be produced with a wire twice as large. Hence it appears, as Mr. Kinnefley remarks, that though the electrical

fire

fire has no fenfible heat when in a ftate of reft, it will, in paffing through bodies, produce heat in them, provided they are proportionally fmall. Thus, in paffing through the fmall wire, the particles are confined to a narrower paffage, and, crowding clofe together, act with a more condenfed force, and produce fenfible heat *.

The difcovery of Dr. Franklin, which eftablifhed the identity of lightning with the electrical fluid, fuggefted an invention, for which we are indebted to the fame philofopher, for fecuring buildings from this moft formidable enemy. The reader will perceive that I allude to that of metallic conductors.

Suppofe Fig. 4. Plate XVI. to reprefent the gable end of a houfe, fixed vertically on the horizontal board F G; a fquare hole is made in the gable end at *h i*, into which a piece of wood is fixed; a wire is inferted in the diagonal of this little piece; two wires are alfo fitted to the gable end; the lower end of one wire terminating at the upper corner of the fquare hole, the top of the other wire is fixed to its lower corner; the brafs ball on the wire may be taken off, in order that the pointed end may be occafionally expofed to receive the explofion.

Experiment.—Place a jar with its knob in contact with the conductor, connect the bottom of the jar with the hook H, then charge the jar, and bring the ball under the conductor, and the jar will be difcharged by an explofion from the conductor to

* Prieftley's Hift. of Elect. p. 394.

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the ball of the houſe. The wires and chain being all in connection, the fire will be conveyed to the outſide of the jar without affecting the houſe; but if the ſquare piece of wood is placed ſo that the wires are not connected, but the communication cut off, the electric fluid, in paſſing to the outſide of the bottle, will throw out the little piece of wood to a conſiderable diſtance, by the lateral force of the exploſion.

Unſcrew the ball, and let the point which is underneath be preſented to the conductor, and then you will not be able to charge the jar; for the ſharp point draws the fire ſilently from the conductor, and conveys it to the coating on the outſide of the jar.

The prime conductor in this experiment is ſuppoſed to repreſent a thunder cloud diſcharging its contents on a weather-cock, or any other metal, at the top of a building; and it may be inferred from this experiment, that if there is a connection of metal to conduct the electric fluid down to the earth, the building will receive no damage; but where the connection is imperfect, it will ſtrike from one part to another, and thus endanger the whole building.

Elevated conductors, applied to buildings to ſecure them from lightning, will in this manner diſcharge the electricity from a cloud that paſſes over them, and a greater quantity of the diſcharge will paſs through a pointed conductor, than through one which terminates with a ball; but whether the diſcharge will be made

made by a gradual current, or by explofion, will depend upon the fuddennefs of the difcharge, on the nearnefs and motion of the cloud, and the quantity of the electricity contained in it. If a fmall cloud hangs fufpended under a large one loaded with electric matter, pointed conductors on a building underneath will receive the difcharge by explofion, in preference to thofe terminated by balls, the fmall cloud forming an interruption, which allows only an inftant of time for the difcharge *.

Vifcount Mahon (now Earl Stanhope) has communicated to the public, in a treatife on this fubject †, fome effentials to be obferved in the erection of conductors to buildings; he advifes, that the upper fifteen or twenty inches of the rod fhould be compofed of copper, and not of iron, as the latter, being expofed to the weather, will ruft, and ruft does not conduct electricity; that the iron part of the rod fhould be painted, but not the upper part of it, becaufe paint is no conductor. He further advifes, that the upper extremity of a conducting rod fhould not only be accurately pointed and finely tapered, but that it fhould be extremely prominent, about ten or fifteen feet above all the parts of the building which are the neareft it. It may be added, that a conductor fhould always be carried in the earth fome feet beyond the foundation of the building, and fhould, if poffible, terminate in water.

* Mr. Adams's Effay on Elect. p. 186.

† Principles of Electricity, p. 205.

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The safest place during a thunder storm is the cellar; for when a person is below the surface of the earth, the lightning must strike it before it can reach him, and will of course, in all probability, be expended on it. Dr. Franklin advises persons apprehensive of lightning to sit in the middle of a room, not under a metal lustre, or any other conductor, and to lay their feet up upon another chair. It will be still safer, he adds, to lay two or three beds or mattresses in the middle of the room, and, folding them double, to place the chairs upon them. A hammock suspended by silk cords would be an improvement upon this apparatus. Persons in fields should prefer the open parts to the vicinity of trees, &c. The distance of a thunder storm, and consequently the danger, is not difficult to be estimated. As light travels at the rate of 72,420 leagues in a second of time, its effects may be considered as instantaneous within any moderate distance. Sound, on the contrary, is transmitted only at the rate of 1,142 feet, or about 380 yards in a second. By accurately observing therefore the time which intervenes between the flash and the noise of thunder which follows it, a very near calculation may be made of its distance, and I know no better means of removing unnecessary apprehensions.

The success of Dr. Franklin, in ascertaining the cause of thunder and lightning, induced succeeding philosophers to apply the same theory to the explanation of the other atmospherical phenomena. From a number of observations, the indefatigable Becca-

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ria endeavours to account for the riſing of vapours and the fall of rain, upon electrical principles; and, it muſt be confeſſed, that if it is not a primary agent in theſe effects, it would be raſhneſs entirely to deny its influence. This philoſopher ſuppoſes, that previous to rain a quantity of electric matter eſcapes from the earth, and in its aſcent to the higher regions of the air collects and conducts into its path a great quantity of vapours. The ſame cauſe that collects will condenſe them more and more, till in the places of the neareſt intervals they come almoſt into contact, ſo as to form ſmall drops, which, uniting with others as they fall, come down in rain. The rain he ſuppoſes to fall heavier in proportion as the electricity is more vigorous.

Hail, he ſuppoſes to be formed in the higher regions of air, where the cold is intenſe, and where the electric matter is very copious. In theſe circumſtances, a great number of particles of water are brought near together, where they are frozen, and in their deſcent collect other particles; ſo that the denſity of the ſubſtance of the hail-ſtone grows leſs and leſs from the center, this being formed firſt in the higher regions, and the ſurface being collected in the lower. Agreeably to this, it is obſerved, that on mountains, hail-ſtones as well as drops of rain are very ſmall, there being but a ſmall ſpace through which they can fall.

Clouds of ſnow differ in nothing from clouds of rain, but in the circumſtance of the cold which freezes them. Both the regular diffuſion of ſnow, and the regularity of the parts of which it confifts, fhew the clouds of fnow to be actuated by fome uniform caufe like electricity *.

Confiftent with this theory is the fact, that vapours never rife to a great height without producing meteors. Almoft all volcanic productions are accompanied with lightning. The column of vapour, which proceeds from the bowels of a volcano, is continually traverfed by lightning, which fometimes feems to proceed from the higher regions, fometimes from the column itfelf. Thefe lightnings were obferved by the younger Pliny, in the eruption which killed his uncle; and Sir William Hamilton has obferved them feveral times. The aurora borealis is alfo generally fuppofed to be electrical; its light feems to be produced by the electric fluid, while it is condenfed in paffing in the columns of elevated vapour †.

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* Prieftley's Hift. Elect. vol. i.

† Mr. Adams's defcription of this meteor, in his Lectures, is as follows: ' The appearances of the aurora come under four different defcriptions. 1ft, A horizontal light, like the morning aurora, or break of day. 2dly, Fine, flender, luminous beams, well defined, and of denfe light. Thefe often continue a quarter, an half, or a whole minute, apparently at reft, but oftener with a quick lateral motion. 3dly, Flafhes pointing upward, or in the fame direction as the beams, which they always fucceed. Thefe are only momentary, and have no lateral motion; but they are generally repeated many times in a minute. They appear much broader, more diffufe, and of a weaker light than the beams: they grow gradually fainter till they difappear; and fometimes continue for

It was intimated that water-ſpouts were among the phenomena, which ſome philoſophers have attempted to explain on electrical principles. A water-ſpout is a moſt

for hours, flaſhing at intervals. 4thly, Arches, nearly in the form of a rainbow: theſe, when complete, go quite acroſs the heavens, from one point of the horizon to the oppoſite point.

'When an aurora happens, theſe appearances ſeem to ſucceed each other in the following order: 1. the faint rainbow-like arches; 2. the beams; and, 3. the flaſhes. As for the northern horizontal light, it appears to conſiſt of an abundance of flaſhes, or beams, blended together by the ſituation of the obſerver.

'The beams of the aurora borealis appear at all places to be arches of great circles of the ſphere, with the eye in the center; and theſe arches, if prolonged upwards, would all meet in one point.

'The rainbow-like arches all croſs the magnetic meridian at right-angles. When two or more appear at once, they are concentric, and tend to the eaſt and weſt; alſo the broad arch of the horizontal light tends to the magnetic eaſt and weſt, and is biſected by the magnetic meridian; and when the aurora extends over any part of the hemiſphere, whether great or ſmall, the line ſeparating the illuminated part of the hemiſphere from the clear part, is half the circumference of a great circle croſſing the magnetic meridian at right-angles, and terminating in the eaſt and weſt: moreover, the beams] perpendicular to the horizon are only thoſe on the magnetic meridian.

'That point in the heavens to which the beams of the aurora appear to converge, at any place, is the ſame as that to which the ſouth pole of the dipping needle points at that place.

'The beams appear to riſe above each other in ſucceſſion; ſo that of any two beams, that which has the higher baſe has alſo the higher ſummit.

'Every beam appears broadeſt at or near the baſe, and to grow narrower as it aſcends; ſo that the continuation of the bounding most formidable phenomenon, and is indeed capable of causing great ravages. It commonly begins by a cloud, which appears very small, and which mariners call the squall, which augments in a little time into an enormous cloud of a cylindrical form, or that of a reversed cone, and produces a noise like an agitated sea, sometimes emitting thunder and lightning, and also large quantities of rain or hail, sufficient to inundate large vessels, overset trees and houses, and every thing which opposes its violent impetuosity.

These water-spouts are more frequent at sea than by land, and sailors are so convinced of their dangerous consequences, that when they perceive their approach, they frequently endeavour to break them by firing a cannon before they approach too near the ship. They have also been known to have committed the greatest devastations by land; though, where there is no water near, they generally assume the harmless form of a whirlwind.

In accounting for these phenomena upon electrical principles, it is observed, that the effluent matter proceeds from a body actually electrified towards one which is not so; and the affluent matter proceeds from a body not electrified towards one which is actually so. These two currents occasion

bounding lines would meet in the common center to which the beam tends.

' The height of the rainbow-like arches of the aurora are estimated by Mr. Dalton to be above the earth's surface about 150 English miles.' Adams's Lectures, vol. iv. p. 542.

two

two motions analagous to the electrical attraction and repulsion. If the current of the effluent matter is more powerful than the affluent matter, which in this case is composed of particles exhaled from the earth, the particles of vapours, which compose the cloud, are attracted by this effluent matter, and form the cylindrical column, called the *descending water-spout*; if, on the contrary, the affluent matter is the strongest, it attracts a sufficient quantity of aqueous particles to form gradually into a cloud, and this is commonly termed the *ascending water-spout*.

A different explanation of these phenomena has been, however, given by other philosophers, and to this it will be proper to advert in the succeeding book, which treats of the nature and properties of air *. In the mean time I shall add a short description

* Mr. Nicholson, who has given both theories, has the following observations, which greatly strengthen the hypothesis which ascribes these phenomena to electricity:—' It was observed of water-spouts, that the convergence of winds, and their consequent whirling motion, was a principal cause in producing that effect; but there are appearances, which can hardly be solved by supposing that to be the only cause. They often vanish, and presently appear again in the same place: whitish or yellowish flames have sometimes been seen moving with prodigious swiftness about them, and whirlwinds are observed to electrify the apparatus very strongly. The time of their appearance is generally those months which are peculiarly subject to thunder-storms, and they are commonly preceded, accompanied, or followed by lightning, the previous state of the air being alike in both cases. And the long established custom, which the sailors have,

tion of one of these wonderful appearances, as given by the celebrated M. Tournefort in his Voyage to the Levant.

"The first of these," says this traveller, "that we saw, was about a musket-shot from our ship. There we perceived the water began to boil, and to rise about a foot above its level. The water was agitated and whitish; and above its surface there seemed to stand a smoke, such as might be imagined to come from wet straw before it begins to blaze. It made a sort of a murmuring sound, like that of a torrent heard at a distance, mixed, at the same time, with an hissing noise, like that of a serpent: shortly after we perceived a column of this smoke rise up to the clouds, at the same time whirling about with great rapidity. It appeared to be as thick as one's finger; and the former sound still continued. When this disappeared, after lasting for about eight minutes, upon turning to the opposite quarter of the sky, we perceived another, which began in the manner of the former; presently after a third appeared in the west; and instantly beside it still another arose. The most distant of these

have, of presenting sharp swords to disperse them, is no inconsiderable circumstance in favour of the supposition of their being electrical phenomena. Perhaps the ascending motion of the air, by which the whirling is produced, may be the current known to issue from electrified points, as the form of the protuberance in the sea is somewhat pointed; and the electrified drop of water may afford considerable light in explaining this appearance.'—*Nicholson's Philosophy*, vol. ii. p. 361.

theſe three could not be above a muſket-ſhot from the ſhip. They all continued like ſo many heaps of wet ſtraw ſet on fire, that continued to ſmoke, and to make the ſame noiſe as before. We ſoon after perceived each, with its reſpective canal, mounting up in the clouds, and ſpreading, where it touched the cloud, like the mouth of a trumpet, making a figure, to expreſs it intelligibly, as if the tail of an animal were pulled at one end by a weight. Theſe canals were of a whitiſh colour, and ſo tinged, as I ſuppoſe, by the water which was contained in them; for, previous to this, they were apparently empty, and of the colour of tranſparent glaſs. Theſe canals were not ſtrait, but bent in ſome parts, and far from being perpendicular, but riſing in their clouds with a very inclined aſcent. But what is very particular, the cloud to which one of them was pointed happening to be driven by the wind, the ſpout ſtill continued to follow its motion, without being broken; and paſſing behind one of the others, the ſpouts croſſed each other, in the form of a St. Andrew's croſs. In the beginning they were all about as thick as one's finger, except at the top, where they were broader, and two of them diſappeared; but ſhortly after, the laſt of the three increaſed conſiderably; and its canal, which was at firſt ſo ſmall, ſoon became as thick as a man's arm, then as his leg, and at laſt thicker than his whole body. We ſaw diſtinctly, through this tranſparent body, the water, which roſe up with a kind of ſpiral motion; and it ſometimes diminiſhed a little of its thicknefs, and again refumed the fame; fometimes widening at top, and fometimes at bottom; exactly refembling a gut filled with water, preffed with the fingers, to make the fluid rife, or fall; and I am well convinced, that this alteration in the fpout was caufed by the wind, which preffed the cloud, and impelled it to give up its contents. After fome time its bulk was fo diminifhed as to be no thicker than a man's arm again; and thus, fwelling and diminifhing, it at laft became very fmall. In the end, I obferved the fea which was raifed about it to refume its level by degrees, and the end of the canal that touched it to become as fmall as if it had been tied round with a cord; and this continued till the light, ftriking through the cloud, took away the view. I ftill, however, continued to look, expecting that its parts would join again, as I had before feen in one of the others, in which the fpout was more than once broken, and yet again came together; but I was difappointed, for the fpout appeared no more."

CHAP. VII.

MEDICAL ELECTRICITY.

Declaration of the Abbé Nollet on this Subject.—Mr. Adams an Advocate for Medical Electricity.—Mode of Application.—Diseases to which it may be applied.—Apparatus most proper for Medical Purposes.

THE declaration of Abbé Nollet, that he received more pleasure from discovering that the motion of fluids in capillary tubes, and the insensible perspiration of animated bodies, were augmented by electricity, than from any other discovery he had made, reflects the highest honour upon his character as a friend of mankind.

Mr. Adams, who was not inferior in humanity and philanthropy to the French philosopher, strongly contends for the medicinal effects of electricity, and brings to aid his arguments the acknowledged property in the electric fluid, to accelerate the vegetation of plants. We may indeed be convinced, by a variety of experiments, that the electric fluid is materially connected with the human frame, and is continually exerting its influence upon it. As the natural equilibrium of this fluid is easily destroyed in the human body, we may safely infer, that any alteration in the quantity or intensity of the action of this powerful fluid will produce correſponding changes in the habit or health of the body. The following experiment proves the effect of this fluid upon organized bodies.

Let the charge of a large jar or battery paſs from the head to the back of a mouſe; if the ſhock is ſufficiently ſtrong, it will kill the animal. If the diſcharge is made in the ſame manner after its death, the fluid will paſs viſibly over the body, and not through it; from which circumſtance we may infer, that the power or medium which tranſmitted the ſhock through the animal is loſt with its life.

The late Dr. Cullen was of opinion, that electricity, when properly applied, is one of the moſt powerful ſtimulants that can be employed to act upon the nervous ſyſtem of animals.

Mr. Adams, therefore, infers, from various experiments, that electricity is applicable to palſies, rheumatiſms, intermittents; to ſpaſm, obſtruction, and inflammation. In ſurgery alſo, he adds, it has conſiderable effect. The gout, the ſcrophula, or king's evil, are ranked among thoſe diſeaſes to which this remedy is applicable; and there is reaſon to ſuppoſe, that in the beginning of theſe diſeaſes its application has been very ſucceſsful.

Modern electricians have contrived various modes for applying the electric fluid to the remedy of diſeaſes.

The ſtream of this fluid may, without a ſhock, be made to paſs through any part of the body; it

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may alſo be thrown upon, or extracted from, any part; and its action in each caſe may be varied, by cauſing the fluid to paſs through materials which reſiſt its paſſage in different degrees; it may be applied to the naked integuments, or to the ſkin covered with different reſiſting ſubſtances; and its power may be rarified or condenſed, confined to one ſpot, or more diffuſed, as the diſcretion of the operator may direct him.

The apparatus the moſt proper for theſe medicinal operations are, an electrical machine with an inſulated cuſhion, properly conſtructed to afford a continued and ſtrong ſtream of the electrical fluid.

Mr. Adams has not only given a deſcription and repreſentation of this apparatus, but has alſo conſtructed them for public utility *, upon a plan recommended by Mr. Birch in his lectures to medical practitioners.

The total want of experimental knowledge upon this ſubject utterly diſables me from deciding upon the efficacy of this remedy. It is certainly a powerful agent in nature, but its effects are tranſient, and the eaſe with which the fluid is tranſmitted through the human body will probably operate againſt its producing a permanent effect. Thus far, however, may with truth be advanced, that it is a ſafe and eaſy remedy, and therefore ſhould never be omitted where there is a chance of its doing

* Adams's Eſſay, p. 313.

 good.

good. Medical men are, however, the only proper judges when it ought to be applied; and it ſhould be a maxim, that the ſafeſt and moſt innoxious medicines may have the moſt fatal conſequences in unſkilful hands.

Book V.

OF AIR.

Chapter I.

HISTORY OF DISCOVERIES RELATIVE TO AIR.

Vague Notions of the early Chemiſts.—Van Helmont.—Choak and Fire Damp.—Mr. Boyle.—Diſcoveries of Dr. Hales.—Of Dr. Black.—Of Dr. Prieſtley.—Of Mr. Cavendiſh.—Of Lavoiſier. Vital or dephlogiſticated Air diſcovered by Dr. Prieſtley.—Compoſition of Water and of Nitrous Acid diſcovered by Mr. Cavendiſh.

THOSE aerial fluids, which in their nature and effects are different from the air of our atmoſphere, did not eſcape the notice of the early chemiſts; but they paid little attention to the nature of them, contenting themſelves with giving them a name which meant nothing, denominating them, in general, *ſpiritus ſylveſtris.*

Van Helmont diſtinguiſhed them by the name of *gas*, which he defined to be a ſpirit or incoercible vapour, as the word *gas*, or rather *ghoaſt*, in the Dutch language, ſignifies. He ſuppoſes the *gas* to have been retained by the ſubſtances from

from which it is extracted, in a fixed or concrete form. He asserts, that sixty-two pounds of charcoal contain sixty-one of gas, and only one of earth, and attributes the fatal effects which workmen experience occasionally in mines to the emancipation of this spirit. On the same principle he accounts for the eructations from the stomach and bowels, and for the floating of drowned bodies; and he concludes by determining, that this gas is a fluid of a nature quite different from that of our common air.

The existence of two different kinds of vapour, or elastic fluids, had been previously observed in mines and coal-works: the one was observed to affect animals with a sense of suffocation, and to extinguish life, and it therefore obtained the name of the *choak-damp*; the other, from the dangerous property of catching fire when a candle or any ignited body was brought in contact with it, was termed the *fire-damp*.

A specimen of the fire-damp, or inflammable air, was collected from a coal-mine of Sir James Lowther, in Cumberland, and brought up in bladders to be exhibited to the Royal Society at London, in the year 1733; and in the year 1736 Mr. John Maud procured, from the solution of iron in oil of vitriol, a quantity of the very same species of inflammable air, and demonstrated that the same might be procured from most of the metals in certain circumstances.

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The experiments of Van Helmont were greatly improved upon by the ſagacious Boyle. He changed the name of gas to that of *artificial air*; he demonſtrated, that this *artificial air* was not always the ſame; for inſtance, that the air produced by fermentation is eſſentially different from that which is formed from the exploſion of gunpowder. He was, I believe, the firſt who perceived that the volume of air was diminiſhed by the combuſtion of certain ſubſtances.

This laſt obſervation of Mr. Boyle ſeems particularly to have attracted the attention of the indefatigable Dr. Hales, and he invented inſtruments for determining the quantities both of the air, which was on ſome occaſions produced, and on other occaſions abſorbed, by different ſubſtances. Theſe experiments deſerve the attention of every philoſopher, and for accuracy or ingenuity have never been exceeded *.

Among other circumſtances, which were particularly remarked by Dr. Hales, was the great quantity of air contained in the acidulated mineral waters; and to this air he ſuſpected they were indebted for their ſparkling and brightneſs, and ſome other of their peculiar qualities. In obſerving the abſorption of air by bodies in combuſtion, he ſaw that this abſorption had its limits: he remarked alſo, in ſome caſes, the alternate production and abſorption of air, as for inſtance in reſpect to the air which he

* See Hales's Vegetable Statics, *paſſim.*

produced from the burning of nitre, which air, he obferved, was very foon diminifhed in bulk, though he did not perceive that the abforption was owing to the water, which he always ufed in his experiments. The production of an air capable of inflammation from the diftillation of certain fubftances did not efcape his obfervation; and he has advanced, that the augmentation of weight in the metallic calces was in fome degree owing to the air which they imbibed. That the phofphorus of Homberg diminifhes the air in which it is burned; that nitre cannot explode in vacuo; and that air is in general neceffary to the cryftallization of falts, are among the facts which are noticed by this philofopher.

From the uncertainty, however, of Dr. Hales and his predeceffors, with regard to feveral material circumftances, of which they appear to have had fome cafual glimpfes, and from their total ignorance of others, the doctrine of the aerial fluids was but in a ftate of infancy, till the decifive experiments of Dr. Black, Mr. Cavendifh, and Dr. Prieftley, furnifhed us with a new fyftem in this important department of natural hiftory.

The firft of thefe philofophers obferved, that lime and magnefia, in their mild ftate, confift of an union of a certain aerial fluid with the earthy bafe; that this aerial matter is actually extracted by the operation of burning, which reduces ordinary calcareous earth to the ftate of quick-lime; and that it is afterwards re-abforbed by the quick-lime when expofed to the air. On this principle he was able,

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not only to account for the loſs of weight by the burning of lime-ſtone, but to eſtimate to the greateſt nicety the additional weight which it could acquire from the atmoſphere. He extracted the gas, to which he gave the name of fixed or fixable air, alſo by another proceſs, namely, by diſſolving the calcareous earth in acids; he found that the cauſticity of lime depended upon its violently attracting from vegetable and animal matter a portion of that air of which it had been deprived, and that upon this principle he was enabled to render cauſtic the alkaline ſalts.

To Mr. Cavendiſh the ſecond place in the order of this hiſtory belongs. He purſued the experiments of Dr. Black, and aſcertained the quantity of fixed air which could be retained by the fixed and volatile alkalis. He accounted for the nature of acidulated waters, by the fixable air which they contained. He procured a ſpecies of inflammable air from ſolutions of iron and zinc in vitriolic acid; and he was the firſt who remarked, that a ſolution of copper in ſpirit of ſalt, inſtead of yielding inflammable air, like that of iron or zinc, afforded a particular ſpecies of air, which loſt its elaſticity by coming in contact with water.

Dr. Prieſtley commenced his philoſophical career by ſome experiments upon fixable air; and the firſt of his communications to the public related to the impregnating of water with this air, by means of chalk and oil of vitriol, a method firſt hinted by Dr. Brownrigg of Whitehaven, and now commonly practiſed in the imitations of the acidulated mineral waters. The Doctor tried the power of fixable air upon animal and vegetable life, and found it fatal to both; and he made ſeveral other valuable experiments, the ſubſtance of which will be related in the chapter on fixed air.

The indefatigable mind of Dr. Prieſtley was not, however, to be ſatisfied with the inveſtigation of a ſingle object. He next turned his attention to the nature of atmoſpheric air. He obſerved, after Dr. Hales, its diminution by different proceſſes, as by combuſtion, &c. but differs as to the cauſe. Dr. Hales ſuppoſed the ſpecific gravity of the air to be increaſed; but Dr. Prieſtley judged, that the denſer part of the air is precipitated, and that the remainder is actually made lighter. The diſcovery that the atmoſpheric air is purified by vegetation is alſo Dr. Prieſtley's.

On purſuing the experiments of Mr. Cavendiſh on inflammable air, the Doctor found that it was not only producible from iron and zinc, but from every inflammable ſubſtance whatever.

Dr. Prieſtley diſcovered the cauſe that air, which has been reſpired, becomes fatal to animal life, to be, that it becomes impregnated with ſomething ſtimulating to the lungs, for they are affected in the ſame manner as when expoſed to any other kind of noxious air. His experiments on the means of reſtoring ſalubrity to air are highly intereſting and entertaining, and afford a pleaſing inſtance of well-directed aſſiduity. But one of the moſt ſtriking diſcoveries

diſcoveries of this philoſopher is, that the nitrous air, which he procured from the ſolution of certain metals in the nitrous acid, had the property of diminiſhing a quantity of the pureſt part of the common air, the remainder being by this proceſs rendered noxious and unfit for combuſtion; and upon this principle nitrous air was for a long time received as a teſt of the purity of the atmoſphere, though it will afterwards appear that this teſt is imperfect. Dr. Prieſtley alſo purſued the laſt-mentioned experiment of Mr. Cavendiſh, and found that a ſimple acid, or alkali, might be made to aſſume the form of a permanently elaſtic fluid; and theſe fluids he diſtinguiſhed by the title of *acid* and *alkaline airs.* But to ſpecify all Dr. Prieſtley's diſcoveries, even in this very conciſe manner, would greatly exceed my limits; I muſt therefore be content with only curſorily mentioning the moſt remarkable.

The publication of theſe experiments of the Engliſh philoſophers excited the attention of ſeveral ingenious foreigners; but the only diſcoveries worthy of notice in this place are thoſe of M. Lavoiſier. The experiments of this philoſopher, aſcertaining the preciſe quantity of water and elaſtic fluid, which are contained in ſlaked lime and mild alkali, alſo thoſe upon the burning of phoſphorus, are the neateſt and moſt complete that have ever been publiſhed. The only new diſcovery of any note, which we can attribute to him, was, demonſtrating that the reduction of metals is owing to the abſorption of a certain elaſtic fluid; but he did not

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at firſt perceive that this fluid was in any reſpect different from the fixable air produced by effervesſcing mixtures. In a memoir, however, which he read, after the publication of his eſſays, before the French Academy, he is of opinion, that the air which is abſorbed by the calcination of metals is common air, but that it is of the very pureſt kind, and more combuſtible and reſpirable than that in which we exiſt.

This opinion verges ſo cloſely upon the dephlogiſticated, vital, or empyreal air of Dr. Prieſtley, that were we not informed by good authority, that M. Lavoiſier firſt received from our Engliſh philoſopher * the hint of extracting air from mercurius calcinatus, the circumſtance would in ſome meaſure affect the priority of his claim to that great diſcovery. Dr. Prieſtley confeſſes, that accident, rather than a preconcerted plan, was his guide upon this occaſion. He had been employed in extracting air from different ſubſtances, and in particular in the converſion of the different acids into fluids permanently elaſtic. Among the ſubſtances from which he endeavoured to extract air was calcined mercury, which afforded it in conſiderable quantities; and upon applying the different teſts, he found this air of a purer nature than the common atmoſpheric air. The air which was produced from red precipitate was equally pure with that which was afforded by the *mercurius calcinatus per ſe.* A ſimilar product

* Prieſtley on Air, vol. ii. p. 36, and 320.

was

was procured from red and white lead, from a variety of ſubſtances moiſtened with ſpirit of nitre; laſtly, from common nitre itſelf, from ſedative ſalt, and Roman vitriol. I omit noticing a number of erroneous opinions, which were ſtarted in the infancy of the ſcience; as my preſent buſineſs is only to trace the ſteps by which our knowledge has been gradually improved in this department of nature.

Dr. Prieſtley continued his experiments on inflammable air, and found that all the metals which yield it when diſſolved in acids, yielded it by means of heat alone; his mode of extracting it was by ſubjecting the filings of the different metals in vacuo to the action of a burning glaſs.

The next remarkable, and perhaps the moſt important diſcovery, was that of Mr. Cavendiſh, which has explained to us the nature and compoſition of water. Mr. Cavendiſh was led to this great diſcovery by the experiment of Mr. Warltire, related by Dr. Prieſtley, in which it was found, that on firing a mixture of common and inflammable air by the electric ſpark, a loſs of weight always enſued, and that the inſide of the veſſel in which it was fired became always moiſt or dewy, though ever ſo carefully dried before. On repeating the experiment, Mr. Cavendiſh did not perceive the diminution of weight which Mr. Warltire ſuppoſed to take place, but the latter effect was completely exemplified. In proſecuting the experiment, it appeared, that it was only the pure or empyreal part, that is about one-fourth, of the common air which was consumed, and the water produced was perfectly tasteless and pure; on mixing empyreal air with the inflammable in a due proportion, the whole portion lost its elasticity, and was condensed into water.

Mr. Cavendish pursued his experiments with remarkable success, to ascertain the constituent principles of phlogisticated air, or that which constitutes the impure and unrespirable portion of the atmospheric air, and by passing the electric spark through common air, and through a certain mixture of empyreal and phlogisticated airs, he was able totally to condense the latter, and to ascertain its constituent principle to be the same with that of nitrous acid, with (as he then thought) a small portion of inflammable matter. In this latter opinion, however, he has since been corrected by Lavoisier, and other modern chymists, who have proved that azote, or phlogisticated air (as it is called by the English chemists) is no other than the basis of the nitrous acid *.

On these experiments and discoveries the whole of the modern system of chemistry and physiology is founded; but their importance will be more completely proved, in treating more at large of the different species of air, and of the succeeding subjects, in these volumes.

* In Mr. Cavendish's Experiment, as he probably used air which had been rendered impure by combustion, some small portion of charcoal or other inflammable matter might be contained in the air.

CHAP.

CHAP. II.

OF OXYGEN GAS, OR PURE, VITAL, EMPYREAL, OR DEPHLOGISTICATED AIR.

Explanation of Terms.—Reasons for the different Names assigned to this Fluid.—How procured.—From Calces of Metals.—By Vegetation.—From Water.—Properties of Oxygen.—A powerful Agent in the System of Nature.—How essential to Flame and Life.—Various Modes provided by Nature for furnishing a Supply of this Fluid.

IT has been already intimated that *gas*, signifying spirit or ebullition, was a term employed by Van Helmont, and other Dutch and German chemists, to describe those elastic fluids, which appeared in their nature different from common or atmospheric air. From the preceding history of fire or caloric, the reader will be at no loss to understand, that every aeriform fluid consists of a *basis*, or matter peculiar to itself combined with the matter of heat, which is indeed the real efficient cause of all fluidity whatever. The word gas has therefore been employed by the French chemists to denote an aeriform fluid composed of a certain basis, which gives it its peculiar character, combined with the matter of heat or fire. It will be also proper to remember, that of those fluids which are termed elastic, some are permanently elastic, as the aeriform fluids, others, such as common vapour from water, are condensible by cold; and that it is only of the former kind that we have now to treat.

The fluid under our immediate consideration was originally termed *dephlogisticated* air, a name given it by Dr. Priestley from supposing it free from phlogiston or inflammable matter; when it was found essential to animal life, it obtained the name of *pure* or *vital air*; and when it was found to contribute essentially to ignition, and the other phenomena of fire, it was termed *empyreal* air; but the French chemists, having discovered that it is the substance which imparts the acid character to all the mineral and vegetable acids, have distinguished it by the name of *oxygen* * *gas*.

Oxygen, or the base of oxygen gas, is naturally or artificially combined with a great variety of substances. From some of these it may be detached by the simple application of heat, since it has a remarkable attraction for the matter of fire, with which, when it unites, it becomes expanded, and assumes the form of gas or air.

The substances from which it may be most easily extracted, by means of heat, are red lead, calcined mercury, nitre, and manganese. Dr. Priestley exposed a quantity of red lead in the focus of a burning glass twelve inches in diameter. A quantity of

* From ὀξὺς (oxus) "sharp or acid," and γείνομαι (ginomai) "to beget or produce."—Oxygen is then literally the principle or substance producing acids.

fixed

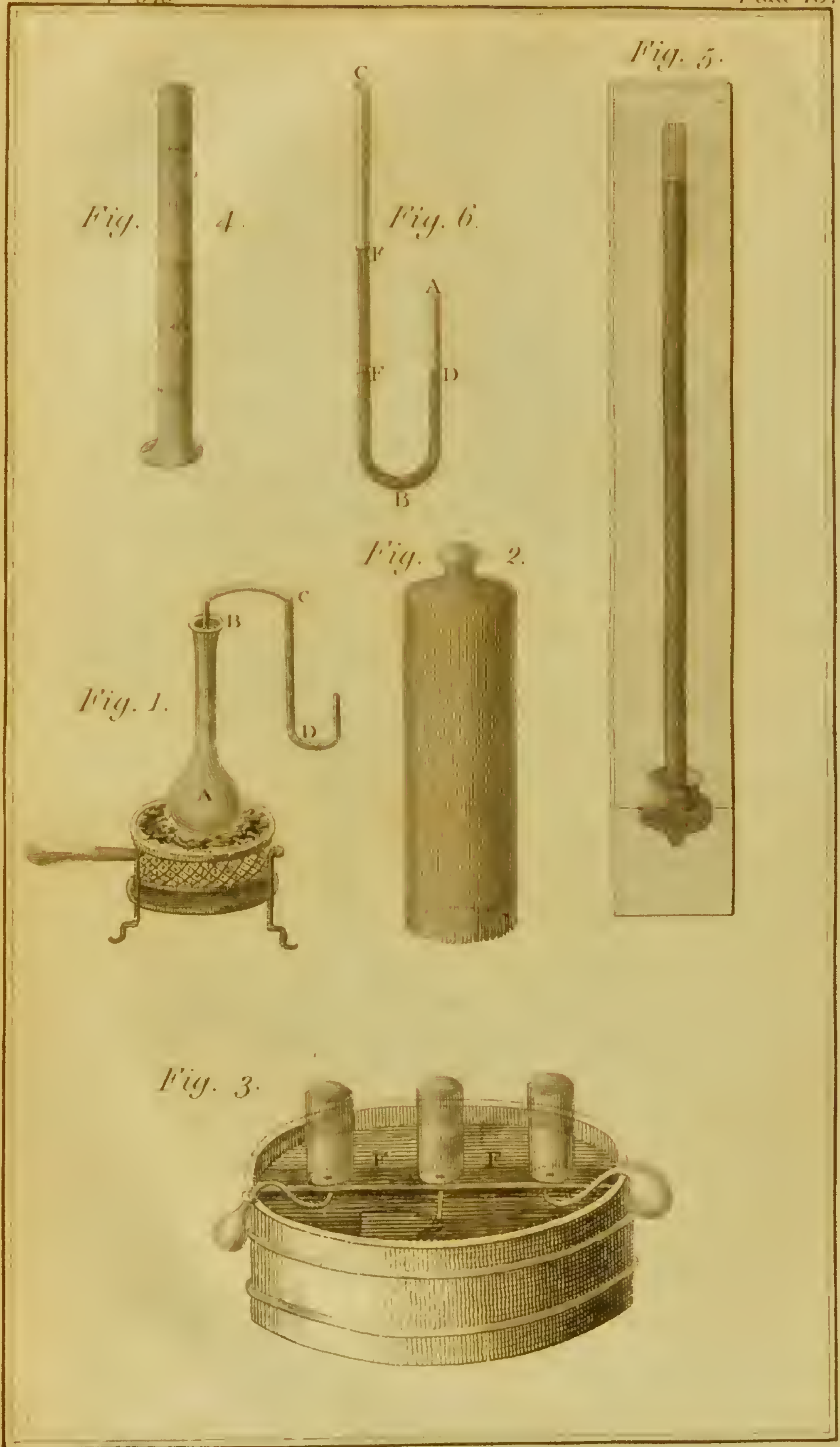
Fig. 5.
Fig. 4.
Fig. 6.
C
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Fig. 2.
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Fig. 3.
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fixed air, or carbonic acid gas, as it is now called, was always produced at firſt; but after that was ſeparated, the remainder was found to ſupport flame, and to ſuſtain animal life much more vigorouſly than common air, and to have all the characters of dephlogiſticated air, or oxygen gas.

By various ſucceeding experiments of Dr. Prieſtley and others it however appears, that dephlogiſticated air, or oxygen, may be obtained not only by means of heat, but alſo by the action of the vitriolic and nitrous acids upon a variety of mineral and metallic ſubſtances.

In a ſmall phial A B (Plate XIX. Fig. 1.) to the mouth of which is fixed a bent tube C D, put an ounce of the oxid of mercury, or hydrargyrus calcinatus; put it to heat over the chaffing diſh R; and after the atmoſpheric air, which filled the phial, is exhauſted, place the extremity D of the bent tube under a long narrow glaſs veſſel (Fig. 2.) filled with the fluid in the pneumatic apparatus or tub (Fig. 3.) and place this veſſel upon the board E F above the aperture *c* or *d* *.

As the mercury revives and becomes liquid, a compreſſible, elaſtic, tranſparent fluid may be obſerved to diſengage itſelf, and paſs into that narrow glaſs veſſel; this is air of the pureſt kind that we are able to procure, namely, vital air or oxygen gas.

This kind of air may alſo be obtained by the

* Traité Elem. de Phyſ. tom. ii. p. 24.

ſame proceſs, from the native oxid or calx of mangancſe, or from minium or red lead, which, it is well known, is an oxid of lead united with nitrous acid.

The better to underſtand theſe effects it muſt be recollected, as was obſerved in the beginning of this chapter, that this fluid is not found in theſe ſubſtances in an entire ſtate; they only contain the baſis of it, which is the oxygen; for metals neither calcine nor burn but in conſequence of their combination with oxygen, which by that means becomes ſolid, and joins its weight with theirs. This oxygen is then expelled by the heat or caloric, which, combining with it, cauſes it to paſs into the ſtate of an elaſtic fluid; during this proceſs, the metal, loſing the oxygen which had reduced it to the ſtate of an oxid or calx, aſſumes its metallic properties, and loſes the weight which it had acquired in becoming oxidated *.

There is, however, a method by which oxygen gas may be obtained with leſs heat and greater facility, and it is as follows; put ſome red lead into a bottle, together with ſome good ſtrong oil of vitriol, but without any water. Let the red lead fill about a quarter of the bottle, and the vitriolic acid be about the ſame quantity, or very little leſs; then apply the bent tube to the bottle by inſerting it through a cork, and having inverted another bottle filled with water in a baſon about half-

* Briſſon, tom. ii. p. 25.

filled

filled alſo with water, direct the other end of the crooked tube into the bottle inverted in the water. In this ſtage of the proceſs we muſt obſerve, that without heat this mixture of red lead and vitriolic acid will not afford any oxygen air, or a very inconſiderable quantity; it is neceſſary, therefore, to apply the flame of a candle or wax taper to the bottle containing the ingredients, while the crooked tube opens a communication between this bottle and that inverted in the water. In this manner the red lead will yield a quantity of elaſtic fluid, which will paſs through the crooked tube into the inverted bottle, and as the quantity of dephlogiſticated air increaſes in the inverted bottle, the water in it will be ſeen to ſubſide; this air will not be all pure, becauſe a conſiderable quantity of fixed air enters with it. In order to ſeparate the fixed from the pure air, the inverted bottle, when filled with the compound of both, muſt be agitated in a baſon of lime water, by which means the lime water will abſorb the whole quantity of fixed air, and leave the dephlogiſticated air or oxygen gas by itſelf.

Oxygen gas may alſo be obtained in conſiderable quantities from water, eſpecially from pump water, which, when expoſed to the ſun, emits air ſlowly; but after it has remained ſo for a conſiderable time, a green matter adheres to the bottom and ſides of the glaſs veſſel in which it remained; afterwards it emits pure air in great quantities, and continues to do ſo for a long time after the green matter has exhibited ſymptoms of decay by turning yellow.

Dr. Ingenhouſz rightly ſuppoſed this green matter to belong to the vegetable kingdom, and procured pure air by putting the leaves of plants into water, and expoſing them to the ſun. He obſerves, that of land vegetables the fitteſt for this purpoſe are the poiſonous plants, ſuch as hyoſcyamus, lauro-ceraſus, night-ſhade, &c. But he extracted the pureſt air from ſome aquatic vegetables, and from turpentine trees, but eſpecially from the green matter he collected from a ſtone trough, which had been kept filled with water from a ſpring near the high road.

While Dr. Prieſtley was engaged in a ſeries of experiments to enable him to purify contaminated air, he diſcovered that vegetables anſwered this purpoſe moſt effectually. The experiment by which he illuſtrates his aſſertion was this; having rendered a quantity of air very noxious, by mice breathing and dying in it, he divided it into two receivers inverted in water, introducing a ſprig of mint into one of them, and keeping the other receiver with the contaminated air in it alone. He found, about eight or nine days after, that the air of the receiver, into which he had introduced the ſprig of mint, had become reſpirable; for a mouſe lived very well in this, but died immediately upon being introduced into the other receiver, containing the contaminated air alone.

It has ſince been obſerved, that ſeveral animal ſubſtances, as well as vegetables, have a power of ſeparating dephlogiſticated air, or oxygen gas, from water,

water, when expofed to the action of the fun for a confiderable time.

The ingenious count Rumford obferves, that raw filk has a remarkable power of producing pure air. He found, that by introducing thirty grains of this fubftance, firft wafhed in water, into a thin glafs globe four inches and a half in diameter, having a cylindrical neck three-fourths of an inch wide and twelve inches long, inverting the globe into a jar filled with the fame kind of water, and expofing it to the action of the fun in the window, in lefs than ten minutes the filk became covered with an infinite number of air bubbles, gradually increafing in fize, till at the end of two hours the filk was buoyed up, by their means, to the top of the water. They feparated themfelves by degrees, and formed a collection of air in the upper part of the globe, which, when examined by the eftablifhed teft, appeared to be very pure. In three days he collected three and three-fourths of a cubic inch of pure air, into which a wax taper being introduced, that had juft before been blown out, the wick only remaining red, it inftantly took fire, and burned with a bright and enlarged flame. The water in the globe had acquired the fmell of raw filk, it loft fomething of its tranfparency, and affumed a faint greenifh caft.

It has been obferved, that when this experiment was made in the dark, only a few inconfiderable bubbles were formed, which remained attached to the

filk;

ſilk; nor was it otherwiſe when the glaſs globe was removed into a German ſtove. In the latter caſe, indeed, ſome ſingle bubbles had detached themſelves from the ſilk, and aſcended to the top, but the air was in too ſmall a quantity to be either meaſured or proved.

In theſe experiments it is probable that the oxygen or pure air was extracted by an actual decompoſition of a part of the water, by means of a capillary attraction, aided by the ſolar influence; and in effect the ſame philoſopher was enabled to extract it, though in a ſmaller quantity, by means of a number of very minute glaſs tubes immerſed in water and expoſed to the ſun.

The properties or functions of this fluid are ſome of the moſt important in nature; nor, except caloric or heat, is there any natural agent more univerſal or more active.

1ſt. It is eſſential to combuſtion; nor do we know of any proceſs by which flame can be ſupported without a ſupply of oxygen gas, or empyreal air.

2dly. In certain proportions it is abſolutely neceſſary to ſuſtain animal life; ſo that the whole animal creation may be ſaid to depend upon this fluid for their exiſtence.

3dly. It is what gives the acid character to all mineral and vegetable ſalts, the baſes of which are found to be entirely inſipid till combined with oxygen.

4thly.

4thly. The calcination of metals is altogether effected by their union with oxygen. Thus for moſt of the mineral pigments, and a very numerous claſs of medicines, we are indebted to this uſeful element.

5thly. It forms a conſtituent part of that neceſſary fluid, water, which conſiſts of 85 parts of oxygen, and 15 of hydrogen, or the baſis inflammable air.

Oxygen gas, or air, is more elaſtic than common air; it exceeds it alſo in ſpecific gravity, for the proportion between pure and common air is as 160 to 152.

On introducing a lighted candle into pure or dephlogiſticated air, the flame becomes larger and brighter; and whenever the air is very pure, the candle burns with a crackling noiſe, as if the air contained ſome combuſtible matter, while the tallow or wax waſtes, or is conſumed, incredibly faſt.

Philoſophers have proved by various experiments, that common air is not diminiſhed by burning; in all theſe experiments the quantity of vapour produced was equal to that abſorbed, or otherwiſe made to diſappear, during the operation. But the caſe is different with oxygen or dephlogiſticated air; for if a burning candle is introduced into a glaſs jar filled with this kind of air, an intenſe heat will take place, which will at firſt expel a ſmall quantity of the air; afterwards, when the candle is extinguiſhed, it will be found that two-thirds of the bulk of air employed will be converted into fixed air. When the fixed air is taken up by

† cauſtic

cauſtic alkali, the ſmall remainder will be as pure as before.

In common proceſſes, not more than one-tenth of the air employed is converted into fixed air. It is probable, that in theſe experiments ſome diminution in the volume of air muſt take place, from the ſuperior gravity of fixed air, and the conſequent condenſation of the other.

If live coals are introduced into a veſſel filled with dephlogiſticated air, it will be found to be diminiſhed one-fourth of its quantity. When this experiment is repeated with ſulphur, the flame will become larger and more vivid than in common air, and three fourths of the quantity will be loſt. If a piece of phoſphorus is put into a ſeven ounce meaſure of this kind of air, the mouth of the bottle being corked, and the phoſphorus being ſet on fire within it, the phial will break in pieces, as ſoon as the flame is extinguiſhed, by the preſſure of the external air.

The purity of vital air is aſcertained by its degree of diminution with nitrous air, or gas obtained from nitrous acid, and this proceſs is to be conſidered as a ſpecies of combuſtion, eſpecially as a conſiderable degree of heat is generated by it. Very great differences, however, are perceived in this reſpect; and according to the quantity of diminution, the air is ſaid to be two, three, or four times better than common air. Dr. Prieſtley mentions ſome extracted from red-lead five times as pure as common air.

Pure

Pure or oxygen air is not absorbed by water, nor soluble in it; but it may, as was just intimated, be almost entirely condensed by nitrous gas, with which it combines, as will be proved when treating of that substance; and this combination is soluble in water, and forms nitrous acid; for this acid is composed of the basis of nitrous gas combined with oxygen, the whole being dissolved in water.

The reason that pure air is the most essential of all the fluids to the support of life is, probably, because a great quantity of heat is necessary for this purpose, and because this fluid contains it in great quantity, and parts with it very freely when it meets with any substance with which it has an affinity. But as its basis (oxygen) combines itself very easily with the basis of coal which is found in the blood and lungs, and, during this combination, loses part of its caloric or heat, which goes to the support of life, the remainder of the caloric and oxygen, combined with the coal, form the acid carbonic gas or fixable air, which is always found to exist in a larger quantity in air which has been respired, than in atmospherical air which has not been subservient to that function. Of this a very easy experiment affords sufficient proof; it is founded on the property which the carbonic gas has of rendering lime water turbid. A crooked tube open at both ends is partly filled with lime-water; a person applies his mouth to one end of the tube, and inspires, by drawing the air through the lime-water contained in it. By this the transparency of the lime-water is is not affected; but it becomes turbid as soon as the person expires, which is owing to the carbonic acid formed in the lungs. It is therefore the great attraction which exists between the matter of coal and the basis of pure air which renders this fluid so proper for breathing. The pure air which we breathe performs two functions equally necessary to our preservation; it carries off from the blood that matter of coal, the superabundance of which would be pernicious, and the heat which this combination deposits in the lungs repairs the continual loss of heat which we experience from surrounding bodies. According to Dr. Priestley and others, the basis of oxygen gas is also absorbed by the blood.

Since, therefore, a great quantity of heat is disengaged from pure air in respiration, it follows, that this fluid must be very pernicious to animals who breathe this air alone for a considerable time; which is consonant with the observations of physicians, who have attempted to cure phthisis by the respiration of vital air.

The basis of this empyreal or pure air, or oxygen, as the French chemists term it, is one of the constituent parts of water. It has been mentioned, that it is also the matter which gives the acid character to all the acids; sulphur, for instance, is a very innoxious, insipid body, till by burning, that is by absorbing oxygen, it becomes vitriolic acid. Whether the basis of this empyreal air is a simple or compound substance, we are unable to determine;

mine; in the preſent ſtate, however, of philoſophical knowledge, we are juſtified in conſidering it as a ſimple elementary body, for it has never yet been decompoſed.

If the limits of this work permitted, or if the reſearches of philoſophers had furniſhed us with ſufficient materials, it would be a moſt pleaſing ſpeculation to trace the wiſdom of Providence in the very ample means which he has provided for ſupplying us with this neceſſary fluid. It is evident, that immenſe quantities of it are, by the various proceſſes of combuſtion, deſtroyed, or, to ſpeak more philoſophically, condenſed, and by its union with inflammable matter formed into water. This water is again raiſed into the atmoſphere in the form of vapour; it falls in dew or rain upon the leaves of plants, and there, by the genial action of the ſolar rays, a new decompoſition again takes place, and every branch, every leaf, every blade of graſs, is occupied in the beneficial function of again impregnating the atmoſphere with this ſalutary fluid. The quantities too, which are abſorbed by the calces of metals, muſt be immenſe; but by the various proceſſes for the ſmelting and reduction of theſe metals, the oxygen is again ſet free, and a freſh ſupply is produced. Even the air, which is injured by reſpiration, is doubtleſs again, by a variety of modes, the greater part concealed from our view, purified, and rendered once more fit for uſe, ſince fixed air, in a diſengaged ſtate, is, comparatively ſpeaking, but a rare ſubſtance in nature, and ſince there

there is reaſon to ſuppoſe that many of the carbonic bodies may be recruited alſo by its decompoſition. Ignorance of nature is proverbially the ſole ſource of atheiſm; and who can contemplate this aſtoniſhing revolution, this circulation of benefits, and not ſmile at the extreme folly of the man, who can ſuppoſe theſe appointments eſtabliſhed without intelligence or deſign.

CHAP. III.

AZOTIC* GAS, OR PHLOGISTICATED AIR.

Azotic Gas is the unrespirable Part of the Atmosphere.—How procured.—Air Bladders of Fishes filled with it.—Its Properties.—Azote the Basis of nitrous Acid.

THE azotic gas is called by Lavoisier mofete, and by Dr. Priestley phlogisticated air. It constitutes about three-fourths of the atmosphere, but is not respirable by itself; whence it derives the name of *azote*, as being unfit for the support of animal life. Philosophers have proved, that this fluid is completely formed in the atmosphere, and that it may be procured by merely absorbing or destroying the pure air, or oxygen, with which it is united in atmospheric air.

Azotic gas, therefore, is always found to remain after a quantity of common air has undergone the respiration of animals, the combustion of bodies, or putrefaction; because in all these cases the pure air

* Or "air which takes away life," from the Greek privative particle α and ζωη (zoê) "life." Dr. Priestley called it phlogisticated air, from supposing it chiefly composed of an imaginary substance, which Scheele and his followers termed phlogiston (or the food of fire); this appellation is now found to be erroneous.

is abſorbed or condenſed. Azotic gas is equally inviſible with common air, and ſomething more elaſtic. Mr. Kirwan procured ſome air, by means of a mixture of iron-filings and ſulphur, ſo perfectly free from vital air, that it was not in the leaſt diminiſhed by the teſt of nitrous air. When this kind of air is ſo produced and dried, by introducing dry filtering paper under the jar that contains it, its weight will be found to be to that of common air as 985 to 1000, the barometer ſtanding at 30.46, and the thermometer at 60°.

Various ſubſtances alſo are productive of this air; and M. Fourcroy has diſcovered, that the air bladders of fiſhes, and particularly of the carp, are full of it; and that it may be collected by breaking them under glaſs veſſels inverted in water. The air, however, which is contained in the bladders of marine plants, is found to be conſiderably purer than atmoſpheric air.

In ſpeaking of the properties of this fluid it is proper to remark, 1ſt. That azotic gas affords no ſign of acidity, not being capable of turning the blue colours of vegetables red*.

2d. It does not precipitate lime diſſolved in water; for if a ſmall quantity of lime water is put into a tube filled with this gas, it will remain clear and

* The common teſt of chemiſts, to prove whether any fluid contains an acid. They commonly drop a ſmall portion of the fluid into a clear phial containing ſyrup of violets; but the moſt delicate teſt is, a paper ſtained with tincture of turnſole or litmus, to which the acid is applied by a feather.

limpid;

limpid; there will be neither lime precipitated, nor chalk formed, which evinces that it is radically different from fixed or carbonic acid air.

3dly. Another property of this gas is that of suddenly extinguishing substances on fire, and killing animals which are plunged into it. This may be proved by introducing an animal, or a burning candle, into a vessel full of this gas; the animal will be suddenly suffocated, and the candle instantly extinguished.

4thly. Azotic gas is rendered respirable by vegetables, which, in certain circumstances, furnish vital air. This property is probably owing to their retaining the hydrogen of the water which they absorb, while they part with the oxygen. There is no doubt that azotic gas is really a constituent principle of the atmosphere; for if seventy-three parts of it are mixed with twenty-seven of pure air, an air will be produced resembling that of the atmosphere, and respirable as that is *.

5thly. It is now a well established fact, that the *azote*, or basis of phlogisticated air, is literally the basis of the nitrous acid †; for being mixed in proper proportions with oxygen or pure air, which is

* Brisson, tom. ii. p. 35.

† It is almost unnecessary to inform the reader, that nitrous acid is that substance commonly sold in the shops under the name of *aqua fortis*. It may seem surprising to be told, that the air which we are commonly breathing is essentially aqua fortis —But though that extremely corrosive and deadly fluid is really composed of azote and oxygen, yet they are then in a state of *combination*, whereas in atmospheric air they are only *mixed*.

neceſſary to give to theſe baſes the acid character, and ſet on fire by paſſing through them an electric ſpark, nitrous acid is uniformly produced, as is evident from the experiments of Mr. Cavendiſh.

6thly. Late diſcoveries have alſo evinced, that the volatile alkali is formed from a union of this gas with hydrogen, or inflammable air.

The further uſes and properties of this air will be better explained when I come to treat of the atmoſphere.

Chap. IV.

FIXED OR FIXABLE * AIR, OR CARBONIC ACID GAS.

The Basis of this Air is the elementary Matter of Charcoal.—Combined with Oxygen.—Modes of producing it.—Fermentation.—Quantity contained in different Kinds of Wines.—Choak Damp.—Properties of Fixed Air.—Great specific Gravity.—May be poured out of a Vessel like Water.—Resists Putrefaction.

IN enumerating the principles of bodies †, it will be recollected, that coal, or *carbon* (according to the French chemists) was considered as a simple elementary substance. Carbonic acid gas, however, is by no means entitled to this character. It receives the name of *carbonic*, because its actual basis is the matter of coal, or, more properly, charcoal. It is called *acid*, because a quantity of oxygen enters into its composition. It is denominated a *gas*, from the matter of fire which gives it the character of a permanently elastic or aeriform fluid. The proportion of the materials which enter into this kind of air is about eighteen parts of oxygen and seven

* So called at first from its supposed quality of existing in a fixed state in certain bodies, as in lime, chalk, &c.

† Book I. chap. 2.

parts of that matter which the French philoſophers denominate carbon, or coal.

If, for example, charcoal is burnt in a cloſe veſſel with oxygen gas, the air which remains after combuſtion is this carbonic acid gas. By the experiments of Lavoiſier and De la Place it appeared, that one ounce of charcoal required for its combuſtion three ounces and one third of vital air, and produced three ounces and an half of fixable air.

There are ſeveral methods of procuring fixed or fixable air, or carbonic acid gas; firſt, by the fermentation of liquors, in which operation its formation is owing to the combination of the carbon of the ſaccharine matter with the oxygen of the water.

It is evident that a great quantity of fixed air is produced, when vegetable or animal ſubſtances (eſpecially the former) are in a ſtate of vinous fermentation. In breweries there is always a ſtratum of fixed air on the ſurface of the fermenting liquor, reaching as high as the edge of the vats; and it is owing to the production and elaſticity of fixed air, that fermenting liquors, when put into cloſe veſſels, often are known to burſt them with great violence.

Dr Prieſtley, in order to determine the quantity of fixed air contained in ſeveral ſpecies of wine, took a glaſs phial (fitted with a ground ſtopple and tube) capable of containing an ounce and half meaſure. This he filled with wine, plunging it into a veſſel of water. The whole was then put over a fire, and the water in which the phial was plunged ſuffered to boil,

boil. The end of the tube in the ſtopple being placed under the mouth of an inverted receiver filled with quickſilver, the heat expelled the fixed air from the wine, which, entering into the receiver, aſcended in bubbles through the quickſilver to the top, removing in its paſſage a part of the metal, and aſſuming its place in the receiver. The reſult of the Doctor's experiment may be intereſting to ſome readers, and to others it may at leaſt afford entertainment.

$1\frac{1}{2}$ oz. of Madeira produced	$\frac{1}{100}$	of an oz. meaſ. of fixed air.
Port 6 years old -	$\frac{1}{48}$	
Hock of 5 years -	$\frac{1}{24}$	
Barrelled claret -	$\frac{1}{12}$	
Tockay of 16 years	$\frac{1}{20}$	
Champagne of 2 years -	2	oz. meaſures.
Bottled Cyder of 12 years	$3\frac{1}{4}$	

Fixed air may be eaſily obtained by mixing together equal parts of brown ſugar and good yeaſt of beer, and adding about twice the quantity of water. This mixture being put into a phial, to which a bent tube with a cork or ſtopple may be adapted, will immediately ferment, and yield a conſiderable quantity of fixed air, which may be received into a phial filled with quickſilver or water.

2dly. Fixed air is produced by the reſpiration of animals; in which caſe the oxygen of the air inſpired furniſhes part of its heat to the ſupport of life, and combines with the carbonaceous or coaly matter, which is disengaged from the blood in the lungs.

3dly. From what has been previously stated it is evident, that fixed air may be produced by the combustion of any carbonaceous or coally matter.

4thly. Fixed air is also extricated in large quantities by the action of acids on calcareous earth.

Fill a phial or a glass receiver with water, and invert it (in the same manner as described in the chapter on dephlogisticated air) in a bason half filled with water. Then put some chalk or marble grossly powdered into another bottle, so as to fill about a fourth or fifth part of it, and pour water upon it until the chalk is covered, then add some vitriolic acid to it, in quantity about the fourth or fifth part of the water, and apply a cork with a tube as before to the bottle, so that the extremity of the tube may pass through the water of the bason into the neck of the other bottle which is inverted in the water. The mixture of chalk and oil of vitriol will then begin to effervesce, and heat is produced, which may be felt by applying the hand to the outside of the vessel. Fixed air is copiously emitted from this mixture, and, passing through the bent tube, will proceed into the bottle inverted in the water, and ascend to the top of it. By these means the inverted bottle may be filled with fixed air, and being corked under water, may be removed from the bason, and kept for use.

5thly. Fixed air is also expelled in large quantities, by the application of heat only, from lime,

chalk,

chalk, magnesia, or alkaline bodies, in what is called their mild state, opposed to caustic; and by the experiments of Dr. Black it was found, that this substance constituted nearly one-third of the weight of those bodies. The alkalies and calcareous earths have consequently a very powerful attraction for this fluid in their caustic state; and it is therefore easily condensed by agitation with lime water, as has been already intimated.

This gas was long known to miners by the name of choak damp, so called from its fatal suffocating effects; and its properties may be enumerated in few words. 1st. It extinguishes flame. 2d. It is fatal to animal life. 3d. It is heavier than common air. 4th. From its acid character it resists putrefaction. 5th. It renders alkalies, &c. mild. 6th. Water, under the common pressure of the atmosphere, and at a low temperature, absorbs somewhat more than its bulk of this gas, and in that state constitutes a weak acid rather agreeable to the taste, whence fixed air is a constituent principle in most mineral waters; indeed the water of springs and rivers is seldom free from it. 7th. It is also a constituent principle of all fermented liquors.

If a lighted wax taper is let down into a bottle filled with fixed air, the flame will be instantly extinguished, and an animal inclosed in a vessel which contains it will immediately expire.

This fixed air will be found to be much heavier than common air; its specific gravity being to that of common air as 151 is to 100.

From

From the greater weight of this gas it always falls to the bottom of the veſſel in which it is contained. An animal introduced into a ſtratum of this air immediately expires; and it is owing to the preſence of this fluid that the Grotto del Cani in Italy is fatal to animals whoſe organs of reſpiration are placed below the level of the mouth of that cavern. This gas may be poured out of one veſſel into another like water, or may be poured on a candle, which it will extinguiſh as effectually as that fluid.

Among the moſt uſeful properties of fixed air, it has been remarked, that water impregnated with it becomes a powerful antiſeptic. Moſt of the famous mineral waters may be imitated by impregnating water with fixed air, and then adding that quantity of ſalt or metal, chiefly iron, which thoſe mineral waters, by analyſis, are known to contain. It is from this property of preventing putrefaction, that fixed air, and vegetables, ſugar, and other ſubſtances, which abound with that principle, are ſuppoſed to be powerful remedies in putrid diſeaſes.

Fixable air not only preſerves fruit, but meat alſo, from putrefaction, and that for a very conſiderable time, and even in the hotteſt weather.

CHAP.

CHAP. V.

INFLAMMABLE AIR OR HYDROGEN GAS *.

This Gas forms the Basis of Water.—Proportion of Hydrogen and Oxygen which enter into the Composition of Water.—Modes of procuring inflammable Air.—Ignes Fatui.—Fire Damp in Mines.—Lightest of all Fluids.—Remarkable Properties.—Use in Air Balloons.—Curious aerial Fire Works.

TO that fluid, which we term inflammable air, the French chemists have given the name of hydrogen gas, because its basis is the peculiar constituent part of water; but what this basis may be in its nature, whether simple or compound, is at present unknown, because it cannot be separated from the heat or caloric which gives it the aerial form, without fixing it in another substance.

According to M. Lavoisier, water is composed of eighty-five parts of oxygen and fifteen parts of hydrogen. This philosopher has instructed us in the following method of obtaining this gas by heat only †.

Let water pass drop by drop through the barrel of a gun, while it remains red hot amidst burn-

* Ὕδωρ (hydor) "water" and γεινομαι (geinomai) "to produce."

† Brisson, tom. ii. p. 73.

ing coals; let a crooked tube placed at the end of this iron, and bent ſo that it may be paſſed into a glaſs veſſel full of water inverted in the pneumatic apparatus. There will then paſs into the glaſs veſſel an aeriform fluid, which is inflammable air or hydrogen gas. In this proceſs the water ſuffers a decompoſition, and while the hydrogen paſſes into the glaſs receiver, the oxygen unites with the ſubſtance of the gun barrel, and oxydates or ruſts its internal ſurface.

By means of acids, however, inflammable air may be obtained in greater abundance, and with more facility. When iron, zinc, or tin, are acted upon by diluted vitriolic, or marine acid, conſiderable quantities of this gas are extricated. In this caſe alſo the water is decompoſed, as is plain from the concentrated vitriolic acid not anſwering the ſame ends as the diluted, either in furniſhing the air or diſſolving the iron, &c.

The apparatus for procuring this gas is the ſame as that which has been deſcribed for producing fixed air, only employing, inſtead of chalk, iron filings, ſmall nails, ſmall pieces of iron-wire, or groſsly powdered zinc. To theſe materials ſome oil of vitriol and water muſt be added in the ſame proportion as in the proceſs for producing fixed air.

The electric ſpark, taken in any ſpecies of oil, produces hydrogen or inflammable air, this ſubſtance being a conſtituent part of all the oils. The ſame may be ſaid of ether, and alcohol or ſpirits of wine, which contain a great proportion of hydrogen.

Mr.

Mr. Cavallo informs us, that he has procured this kind of air from the ponds about London, in the following manner. Fill a wide mouthed bottle with pond-water, and keep it inverted in it; then with a ſtick ſtir the mud at the bottom of the pond juſt under the inverted bottle, ſo as to permit the bubbles of air which riſe to be received in the inverted bottle; and this air will be found to be inflammable.

The ignes fatui are ſuppoſed to proceed from the inflammable air which abounds in marſhy grounds, and to be ſet on fire by electric ſparks.

This gas, as well as fixed air, was long known to miners before it was noticed by philoſophers; and among the colliers and other workmen of that claſs, it obtained the name of the fire damp. It is however ſeldom found pure in mines or coal works, but is generally combined with ſulphureous matter, or what is called hepatic gas, or with carbonic acid air; and this admixture varies its ſpecific gravity, and in general renders it ſomething heavier than pure inflammable air. The fire damp generally forms a whitiſh cloud in the upper part of the mine, and appears in ſomething of a globular form; from its levity it will not mix with the atmoſpheric air, unleſs ſome agitation takes place; and it is diſpoſed to lodge in any little cavity in the ſuperior part or roof of the mine. When it appears in this form, the miners generally ſet fire to it with a candle, lying at the ſame time flat on their faces to eſcape the violence of the ſhock. It will not, however, take fire

fire unless in contact with atmospheric air, for the obvious reason, that a mixture of oxygen gas is necessary to its inflammation. The danger arises entirely from its inflammability on the approach of any ignited body, for when the fire damp consists of pure inflammable air, the explosion is like that of gunpowder; but when it is mixed with carbonic acid, it burns with a lambent flame. The easiest and safest method, therefore, of clearing the mine from this formidable fluid is by leading a long pipe through the shaft of the mine to the ash-pit of a furnace, when the inflammable vapour will be constantly attracted to feed the fire.

Dr. Priestley has sufficiently proved by experiments, that there is no acid contained in inflammable air. He also asserts that charcoal, by the heat of a burning lens, may be almost totally converted into this kind of air, but that some moisture is necessary in the process. The necessity of moisture, however, to the success of this experiment, sufficiently evinces the fallacy of the conclusion which has been drawn from it. Perfectly pure charcoal, abstracted from every other body, is indestructible by heat. Where, however, there is moisture there is water. In this case the oxygen of the water is attracted by the carbon, forming with it carbonic acid, and the hydrogen, the other constituent part of water, rises to the top of the receiver. Pure hydrogen gas is the lightest of all elastic fluids, its specific gravity is to that of common air as 8,04 is to 100,00 *.

* Brisson, tom. ii. p. 77.

The

The most remarkable properties of this gas are, 1st, its great inflammability, which arises from its propensity to unite with oxygen and form water. 2dly. Its extraordinary levity, as already noticed. 3dly. Metals are very easily revived or reduced from a calx or oxyd to the metallic state when heated in a receiver filled with this air. This also arises from its attraction for oxygen, which in this case is expelled from the calx, and, uniting with the hydrogen in the receiver, leaves the metal pure, and in its natural state. 4thly. Plants vegetate in this fluid without impairing its inflammability. 5thly. Water will imbibe about one-thirteenth of its bulk of this gas, which may be again expelled by heat, and will then be equally inflammable as before. 6thly. Hydrogen gas, or inflammable air, is fatal to animal life; in proof of which Mr. Cavallo relates, that the Abbe Fontana, having filled in his presence a large bladder with inflammable air, began to breathe it, after having made a violent expiration. The first inspiration produced a painful oppression on his lungs; the second caused him to look pale; and the third was scarcely accomplished, when he fell on his knees through weakness. Small animals are also killed by a very few inspirations of this noxious fluid. 7thly, This gas is said to have a smaller share of refractive power than common air.

It is on account of its lightness that hydrogen gas has been most frequently employed in aerostation. The method of filling a balloon is only enlarging the process which has been described for producing inflammable air on a small scale.

Very pleafing fireworks may be made from this gas, by filling bladders with it, and fixing brafs cocks to them, by means of which the gas may be difperfed into any number of glafs tubes bent in various fhapes, and with fmall holes in various parts of them; then by preffing the bladders more or lefs, as occafion may require, the gas will pafs into the tubes, and iffue out of the fmall holes, to which a lighted taper may be applied; by thefe means the air will take fire, and will continue to burn until the courfe of it is ftopped by fhutting the cock at the neck of the bladder. Thefe aerial fireworks may be made to reprefent different figures, either moveable or immovable, and may be ornamented with different colours. The white coloured flame is produced by hydrogen gas procured from common coal; again, by mixing an equal quantity of this air with atmofpheric air, a flame of a blue colour will be produced; the pure hydrogen from metals furnifhes a red flame; and if by breathing, fome carbonic acid gas or fixable air is added, the flame will appear beautifully tinged with purple *.

* See Briffon, tom. ii. p. 81.

CHAP. VI.

NITROUS AIR OR GAS.

Nature of this Fluid.—How produced.—Its Properties.—Resists Putrefaction.—Absorbs and condenses pure Air.—The Eudiometer.

NITROUS gas ought properly to be considered as an intermediate state of that elementary substance which is the basis both of azotic gas and nitrous acid. Azote, perfectly saturated with oxygen, forms pale nitrous acid; with a smaller portion, it constitutes the ordinary orange-coloured and fuming nitrous acid; with still less, it becomes nitrous gas; and when wholly uncombined with oxygen, is denominated azotic gas. In the state of azotic gas it is insoluble; but in proportion to the quantity of oxygen with which it is combined, its disposition to assume an aeriform state is diminished, and its attraction for water increased.

In order to produce nitrous air, put copper, brass, or mercury, first into the bottle (with the same apparatus as for the other airs) so as to fill about one third of it, then pour a quantity of water into it, so as just to cover the metal filings; and, lastly, add the nitrous acid, in quantity about one half or one third,

third, according to the ftrength which is required. Nitrous air contains, in 100 grains, 68 of oxygen, and 32 of azote.

On its relation to the nitrous acid the diftinguifhing properties of this gas will be found to depend.

1ft. Nitrous air is as invifible and tranfparent as common air; in its fmell it refembles nitrous acid. Though this kind of air extinguifhes flame, it may, by certain proceffes, be brought to fuch a ftate, that a candle will burn in it with an enlarged flame, and it then becomes what Dr. Prieftley calls *dephlogifticated nitrous air*. Its fupporting flame in this inftance evidently depends on the large quantity of oxygen which enters into its compofition.

2d. When oxygen or empyreal air is added to nitrous air, it imparts to it the acid character, and it becomes true nitrous acid. Mr. Cavendifh impregnated fifty ounces of diftilled water with fifty-two ounce meafures of nitrous air, mixed with as much common air as was neceffary to decompound it. The water thus impregnated was fenfibly acid, and being diftilled, the firft runnings were very acid, and fmelt pungent: what came next had no tafte or fmell; but the laft runnings were very weak nitrous acid *.

3d. Of all the different fpecies of air, this feems the moft noxious to animal life. Infects, which can bear azotic and inflammable air, will die imme-

* Phil. Tranf. for 1784.

diately

diately upon their being immerfed in this. Even fifhes will not live in water impregnated with it.

It may feem extraordinary that nitrous gas, which is of fo deleterious a nature, and fo oppofite in its qualities to common air, fhould yet fubftantially confift of the fame principles, differing, however, in the proportions. To remove the difficulty, it will be neceffary to recollect what has been more than once intimated concerning the difference between *mixture* and *combination.* In fimple mixture the two bodies ftill retain their own diftinct properties; but in chemical combination a third fubftance is formed from the two, entirely different from both in its nature and properties. Thus, from marine acid or fpirit of falt, and cauftic alkali, both extremely corrofive, is formed that innocent and wholefome fubftance, common falt; and from two fubftances innoxious to the human frame, fulphur and oxygen, vitriolic acid, or fpirit of vitriol, is formed. In common air, azote and oxygen are indeed in a ftate of mixture, but they are not combined; for to make them enter into a ftate of combination, the operation of a ftrong agent, fuch as fire from the electric fpark, is neceffary, and without this, azote appears to have little or no attraction for oxygen. In the ordinary procefs of refpiration the mixed fubftances are inhaled; and it is probable that they are foon again feparated in this procefs, and each differently difpofed of. In nitrous gas, the azote and oxygen are in a ftate of chemical combination, and it is a third fubftance different in qualities from both; it is,

 indeed,

indeed, an imperfect nitrous acid in an aerial form; though azote, therefore, in its simple uncombined state, has no attraction for oxygen, it is different when by combination it becomes an acid; it has then a strong attraction for that substance which is necessary to give it the true acid character, and it will absorb it till it arrives at what the chemists call the point of saturation, that is, till it is made a perfect acid; and this is the reason that it so rapidly attracts and condenses the pure part of the atmosphere.

4th. Nitrous air possesses the property of preserving animal substances from putrefaction, and of restoring those already putrid, in a still greater degree than fixed air, and on this the antiseptic power of nitre may, perhaps, chiefly depend. On putting two mice, the one just killed, the other putrid and soft, into a jar of nitrous air, and letting them continue in it twenty-five days, in the months of July and August, there was little or no change in the quantity of air; both mice were perfectly sweet; the first quite firm, the flesh of the second still soft, but not in the least putrid. From these experiments Dr. Priestley recommends nitrous air as an antiseptic. Unfortunately, however, though animal substances may be preserved from putrefaction for several months by nitrous gas, yet they become dry, distorted, and offensive to the palate, so as to render the discovery of little public utility.

5th. The specific gravity of nitrous air is to that of the atmosphere as 1195 to 1000.

6th. One

6th. One of the moſt remarkable properties of this air is, that it condenſes or diminiſhes in bulk with oxygen or dephlogiſticated air, by which means it becomes a teſt with reſpect to the quantity of that pure element contained in the atmoſphere. With pure dephlogiſticated air the diminution is almoſt to nothing, at the ſame time that nitrous acid in ſome quantity is reproduced by the decompoſition of the nitrous air; but as our atmoſphere is always mixed with a conſiderable quantity of azotic or phlogiſticated air, on which nitrous air has no effect, the diminution in this caſe is never ſo conſiderable. Upon this principle the eudiometer for meaſuring the purity of air is formed.

To underſtand the nature of this inſtrument, let a glaſs tube (Fig. 4.) of about nine inches long, cloſed at one end, and of about three-fourths of an inch diameter, be filled with and inverted in water; then take a phial of about half an ounce meaſure, filled with common air, and plunging it under the water contained in the ſame baſon with the inverted tube, let that quantity of air enter into the tube; it will then riſe to the top of the tube while the water ſubſides. Let a mark be made on the tube at the height of the water in it, to ſhow how much of the tube is filled by that meaſure of air. In the ſame manner inject four or five meaſures of common air, marking the height of the water at every one reſpectively. After this proceſs, if three meaſures of either nitrous or common air are introduced into the tube, they will cauſe the water to ſubſide to the third mark; but if two meaſures of common air and one meaſure of nitrous air, or one meaſure of the common and two of the nitrous air, are put into the tube, they will fill a ſpace much ſhort of the third mark. When theſe two kinds of air come firſt in contact, a reddiſh appearance is perceived, which ſoon vaniſhes, and the water, which at firſt nearly reached the third mark, riſes gradually into the tube, and becomes nearly ſtationary after about two or three minutes, by which it appears, that the diminution takes place gradually.

Nitrous air is neither ſoluble in water nor poſſeſſes any ſigns of acidity; for it has not the power of changing the blue colour of vegetables red, unleſs it is mixed with common or dephlogiſticated air, by which it acquires the true acid character *.

* Briſſon, tom. ii. p. 39.

CHAP.

CHAP. VII.

OF HEPATIC GAS.

Nature of this Gas.—Means of producing it.—Its Properties.—A chief Constituent of Sulphureous Mineral Waters.—Turns Metals Black.—How decomposed, &c.

M. Gengembre, who has made an analysis of this kind of air, regards it as proceeding from pure hydrogen and sulphur. The most proper method of obtaining this air is by pouring marine acid on liver of sulphur *, which extricates it in considerable quantities. It is equally produced from all livers of sulphur, whether they are made with alkalis or earths. By various experiments, however, it now seems to be ascertained, that as hepatic gas is composed of sulphur and hydrogen in certain proportions, it cannot be produced except water is present, the decomposition of which affords the hydrogen. Thus, if marine acid air is applied to very dry liver of sulphur, scarcely any hepatic gas is produced, from the defect of humidity. Liver of

* A substance usually formed from fixed alkali, or salt of tartar, and sulphur combined by heat.

ſulphur, when heated, affords hepatic gas with the addition of mere water without acid. In this caſe alſo the water is decompoſed; its hydrogen unites with part of the ſulphur to form hepatic gas, while the oxygen of the water uniting with another part, produces vitriolic acid, and this with the alkali forms a neutral ſalt which may be eaſily obtained.

1ſt. Hepatic gas is very ſoluble in water, which it converts into a ſtate perfectly reſembling that of ſulphureous mineral waters. 2d. It detonates with vital air when ſet on fire. 3d. It is not clearly aſcertained in what manner ſulphur is ſuſpended in hepatic gas. Sulphur melted by a burning glaſs, in inflammable air over mercury, produces a fluid which has the properties of hepatic gas; and if inflammable air is paſſed through ſulphur in fuſion it is converted into hepatic gas. 4th. The ſmell of this air is very unpleaſant, and its vapour has a very diſagreeable effect, upon many metallic ſubſtances, particularly ſilver, lead, copper, &c. deſtroying their colour, and rendering them almoſt black. 5th. It is extremely pernicious in reſpiration. 6th. It may be decompoſed by vitriolic and nitrous air, by vital air, and by the contact of atmoſpheric air, in which caſe it depoſits ſome ſulphur. Its great attraction for ſome of the metals and their calces makes it the baſis of ſome ſympathetic inks.

The volatile alkali, and moſt of the acids, may be made to aſſume an aerial form, and have been diſtinguiſhed

diſtinguiſhed under the appellation of alkaline and acid airs; it is unneceſſary, however, to introduce the ſubject in this place, and it will be better underſtood when the acids and alkalies are treated of, as they will be in the ſucceeding book.

Chap. VIII.

OF ATMOSPHERIC AIR.

Atmoſphere compoſed chiefly of Two Kinds of Air.—Contains alſo Fixed Air, and occaſionally other Subſtances.—Effects of this Mixture on Metals and Purple Dyes.—Means of purifying the Atmoſphere from Fixed Air, and putrid Vapours.—Effects of Moiſture contained in Air.—The Hydrometer.—Cold in the higher Regions of the Atmoſphere.—Cauſe.

WHATEVER has been hitherto ſtated relative to the different ſpecies of elaſtic fluids is chiefly important, becauſe the knowledge of theſe fluids is neceſſary to enable us to comprehend the nature of that atmoſphere in which we exiſt, and which is indeed of itſelf one of the principal agents of our exiſtence.

In treating ſeparately of the different kinds of air, it was neceſſary in ſome meaſure to anticipate the preſent ſubject, and to intimate that the air of our atmoſphere is not, as was formerly ſuppoſed, a ſimple homogeneous fluid, but that in reality it is compoſed of two different fluids, which have been deſcribed under the appellations of azotic and oxygen gas, or phlogiſticated and vital air.

In one hundred parts of atmoſpheric air there are contained about ſeventy-two parts of azotic gas to to twenty-ſeven of oxygen, beſides one part of carbonic acid gas or fixed air, which is generally found united with them, or to ſpeak in round numbers, in order to be better underſtood, we may ſay that the air of our atmoſphere contains rather better than one fourth of pure or reſpirable air, and that the remaining three fourths are unfit for reſpiration, and equally unfit for combuſtion, ſince the ſame fluid which ſupports flame is found equally to contribute to the ſupport of animal life.

By the combuſtion of any inflammable ſubſtance in a cloſe veſſel filled with atmoſpheric air, it will be found that about a fourth part of the whole bulk of the air will diſappear, and that the combuſtion will gradually ceaſe in proportion as that fluid is diminiſhed which is neceſſary to its ſupport.

The ſame quantity is deſtroyed by the proceſs of reſpiration. Putrefaction alſo ſeparates the pure air; and the power of ſeparating, and alſo of reuniting the two fluids, which laſt may be done, when both are produced by artificial means, very ſufficiently proves them diſtinct in their nature and properties, and alſo that they are united in the air of our atmoſphere.

Azotic gas being ſpecifically lighter than oxygen, it might naturally be ſuppoſed, that ſince they only exiſt in the atmoſphere in a mixed ſtate, and not in a ſtate of chemical combination, a ſpontaneous ſeparation would take place, and that the azote would occupy the higher regions of the atmoſphere;

whereas

whereas it is found by experiments with the eudiometer, that the upper regions of the air actually contain a greater proportion of oxygen than thofe nearer the furface of the earth. Whether this is to be attributed to the attraction which azote may have for the earth, or to fome unknown property in the oxygen, we cannot now determine, and can only take the fact as it ftands, without attempting its explanation *.

From the great confumption of oxygen by various natural and artificial proceffes, it might be expected that a deficiency of this fluid in the atmofphere might fometimes occur; but the wifdom of Providence is evident in this, as well as in every other inftance; for we have already feen that the proceffes in nature which deftroy this air are nearly balanced by thofe which produce it. A feries of experiments were made at Stockholm by the indefatigable Scheele, to afcertain the goodnefs of the air during every day in the courfe of a year. He found that the diminution by the eudiometer never exceeded one-third, nor was lefs than eight thirty-thirds. The quantity of vital air was leaft in March, November, and December, and in general lefs in the winter than in the fummer months, which may be attributed to the redundant fupply of this matter by the copious vegetation which takes place at that period. The air

* A mixture of empyreal and inflammable airs remaining all night, was found the next morning in the moft perfect ftate of mixture, and the electric fpark paffed through them with the ufual effect. *Prieftley's Experiments.* Vol. vi. p. 27.

at

at ſea is generally found in a purer ſtate than at inland places.

Extraordinary as this mixture of fluids in the atmoſphere may appear, it is eſſential to our health, and even our exiſtence, and demonſtrates no leſs the wiſdom and goodneſs of Providence, than all his other beneficial appointments. This pure vital air, ſays Briſſon, ſo wholeſome, ſo neceſſary in a moderate quantity; like ſpirituous liquors, or ſalutary medicines, muſt be uſed with precaution, and would be fatal in the exceſs. If we were indeed to breath pure or oxygen air without any mixture or alloy, we ſhould infallibly periſh by the unnatural and fatal accumulation of heat in our bodies; if, again, the whole atmoſphere was compoſed only of vital air, combuſtion would not proceed in that gradual and moderate manner which is neceſſary to the purpoſes of life and of ſociety; and even iron, and the metals themſelves, would blaze with a rapidity which would carry deſtruction through the whole expanſe of nature.

The air of our atmoſphere is, however, not ſo ſimple a ſubſtance as to be formed only of two ingredients. Beſides the ſmall portion of carbonic gas or fixed air which it contains, equal to one hundredth part, as was intimated in the beginning of this chapter, it is alſo well known that a large portion of water is uſually held in the atmoſphere, ſometimes in a ſtate of perfect ſolution, or entirely inviſible, and ſometimes viſible in the form of miſts and clouds. The atmoſphere is alſo the general recipient of all thoſe ſubſtances which are ſubject to evaporation, and which preſerve their aeriform ſtate under its ordinary heat and preſſure.

From the mixed nature of the maſs, and particularly from the mixture of carbonic acid gas or fixed air, ſeveral effects are produced, and ſome of them it may be proper to notice. Fixed air being in reality an imperfect acid, contributes to ruſt metals, and to change the colour of ſuch purple dyes as are produced from vegetable ſubſtances. This is an effect which moſt perſons have noticed, though the cauſe has not been underſtood; and the delicate nature of theſe colours has been almoſt an invariable objection againſt their uſe.

The air of the atmoſphere is moſt generally injured by the deſtruction of the pure part, and the generation of carbonic acid gas, as in moſt of the proceſſes of combuſtion, and in that of reſpiration. When it is neceſſary to purify the air from the carbonic acid, which may be too abundant in it, any contrivance for bringing it into contact with lime-water will ſufficiently anſwer this purpoſe. A cloth dipped in that liquor, and ſuſpended near the floor, will generally purify the air of a room from any contamination of fixed air.

Combuſtion or reſpiration are, however, not the only means by which atmoſpheric air is injured. Phoſphorus of every kind, liver of ſulphur, oil of turpentine, cements of wax, oils of mint, cinnamon, &c. nitrous acid, and even nitrous æther, at once diminiſh and deprave it.

The air is alſo rendered unwholeſome by the abſorption of putrid* or inflammable vapours, the exploſion of gunpowder, by oil paints, by the volatile ſpirit of ſal ammoniac, by ſpirits of wine, by every kind of perfumery or artificial ſcents, by the vapour of new plaiſtered walls, by all putrid ſubſtances, and eſpecially by ſtagnate water; theſe ſubſtances all diffuſe a quantity of inflammable air or vapour through the ſurrounding atmoſphere, and ſome of them conſume the pure or vital part. Even the vapour of pure water in conſiderable quantities is pernicious to animal life; Muſchenbroek obſerved, that it threw a bird into great anxiety; that the vapour of vinegar had a ſimilar effect; that the vapour of ſpirit of wine killed a bird; and that ſeveral others were fatal to life †.

From theſe facts it is manifeſt that the burying of the dead in populous towns is a wretched and dangerous mockery of police. I know a certain great town where, in burial places in the very middle of the town, the dead are buried not ſix inches below the ſurface; and in London, notwithſtanding the act of parliament, what with the preſent evaſion of

* A quantity of corrupted fiſh were once thought to have occaſioned a violent epidemic fever at Venice. The ſame effect was produced at Delft, by the corruption of vegetables. The Arabs, when deſirous of injuring the Turks at Baſſora, break down the banks of the river near that city, ſo as to permit it to overflow a great tract of land; a violent fever is generally the conſequence of the putrid mud, &c. which is left behind after the water is evaporated.—*Cav. on Air,* 457.

† Cavallo on Air, p. 447.

that

that aćt, the depofiting in vaults, and the frequent breaking up of the ground, and removing putrid bodies, the cafe is not much better; and indeed much might yet be done to render the air of London more falubrious than it is.

I have taken no notice of the accounts which fome ingenious men have afforded us of the falubrity of the air in different places, convinced that we are not as yet poffeffed of a complete teft of the falubrity of air; and till this can be procured our only guide muft be experience.

By agitating putrid and inflammable air in diftilled water, or water from which the air has been expelled by boiling, a confiderable diminution will take place, fometimes above a third of the bulk, and the air will be confiderably purified. Thus the agitation of the fea, and of large lakes, has probably the happieft effećt in purifying the atmofphere.

Dr. Hales found that air might be breathed much longer, when in the aćt of refpiration it was made to pafs through feveral folds of cloth dipped in vinegar, a folution of fea falt, or oil of tartar, than when no fuch contrivance was ufed; the reafon of which is briefly, that thefe fubftances abforb the fixable air which comes from the lungs *.

Putrid air was alfo reftored by a mixture of carbonic acid air. The experiment was, however, in fome meafure rendered doubtful by the air having been paffed through a veffel of water in order to its admixture. If, however, the fact is well found-

* Hale's Eff. p. 266.

ed,

ed; lime kilns in the vicinity of populous cities may poſſibly not be ſo unwholeſome as is generally imagined, as in thoſe places the putrid air and vapours abound more than the carbonic acid.

The eudiometer is a good teſt of air as far as regards the diminution of the oxygenous part; but it is on the whole an imperfect inſtrument, as it affords no means of diſtinguiſhing the deleterious vapours with which the atmoſphere may occaſionally be charged.

Beſides their deleterious properties, the mixture of watery particles and vapour in air has alſo conſiderable effect with reſpect to its power of conducting heat from our bodies. The rarity or denſity of air ſeems to have little effect with reſpect to its conducting power, which indeed appears entirely to depend on the quantity of moiſture it contains. A moiſt air conducts heat with much greater rapidity than a dry air. Whence (ſays the ingenious Count Rumford) 'I cannot help obſerving with what infinite wiſdom and goodneſs, Divine Providence appears to have guarded us againſt the evil effects of exceſſive heat and cold in the atmoſphere; for were it poſſible for the air to be equally damp during the ſevere cold of the winter months, as it ſometimes is in ſummer, its conducting power, and conſequently its apparent coldneſs, when applied to our bodies, would be ſo much increaſed by ſuch an additional degree of moiſture, that it would become quite intolerable; but, happily for us, its power to hold water in ſolution is diminiſhed, and with it its power to rob us of our animal heat, in proportion as its coldnefs is increafed. Every body knows how very difagreeable a very moderate degree of cold is when it is very damp; and hence it appears, why the thermometer is not always a juft meafure of the apparent or fenfible heat of the atmofphere. If colds or catarrhs are occafioned by our bodies being robbed of our animal heat, the reafon is plain why thofe diforders prevail moft during the cold autumnal rains, and upon the breaking up of froft in the fpring. It is likewife plain, whence it is that fleeping in damp beds and inhabiting damp houfes is fo very dangerous, and why the evening air is fo pernicious in fummer and autumn, and why it is not fo in the hard frofts of winter. It has puzzled many to account for the manner in which fuch an extraordinary degree, or rather quantity, of heat is generated, which an animal body is fuppofed to lofe if expofed to the cold of winter, which it communicates to the furrounding atmofphere in warm fummer weather; but is it not more than probable, that the difference of the quantities of heat actually loft or confumed, is infinitely lefs than what they have imagined *?'

Various inftruments have been invented under the general name of hygrometers †, for afcertaining the quantity of moifture contained in the atmofphere.

* Thompfon's Experiments. Phil. Tranf. Vol. lxxvi.

† Ὑγρος, (hygros) "moifture;" and Μέτρον, (metron) "a meafure."

mofphere. Moft bodies attract moifture, and are expanded by it. Wood and other folid bodies are fwelled by the moifture infinuating itfelf between the fibres, and confequently a piece of wood cut tranfverfely, will be extended in length by the abforption of damp or wet. Cord, catgut, &c. the fibres of which extend longitudinally, will increafe in thicknefs, but will contract in length on the application of moifture. On this laft principle the common weather-houfe is conftructed, which is no bad hygrometer for general purpofes; the contraction of the ftring by wet forces the man out of the door, and when by the return of fine weather the ftring or catgut is difpofed to refume its natural length, an elaftic wire acts upon it, and the woman appears. The firft regular and graduated hygrometer that deferves to be mentioned, as made in this country, was that of the late ingenious Mr. Smeaton. He employed in its conftruction a flaxen ftring of three threads, commonly ufed in making nets, which, in order to make it attract the moifture readily, he fteeped in falt and water. This he extended along a board properly graduated, and to one part contrived to attach an index, which ferved to fhew its variations. M. Sauffure employed a hair for the fame purpofe, which he fufpended by a weight of three grains, and contrived it to act upon an index pointing to a graduated fcale; and this was found to be a very delicate and accurate inftrument.

M. de Luc, however, conceived that a folid body would afford the moſt accurate and ſteady meaſure of damp or dryneſs, and was leſs likely to be out of order than fibrous and twiſted ſubſtances. He ſucceſſively employed ivory, box-wood, and whalebone; but after ſeveral trials preferred the latter, becauſe of its great power of expanſion, which ſometimes exceeded one-eighth of its length, and becauſe of its ſteadineſs, in always coming to the ſame point in extreme moiſture. His hygrometer therefore conſiſts of a very thin ſlip of whalebone, about 12 inches in length, and a line in breadth, cut tranſverſely to the direction of the fibres. This he extends by a ſmall ſpring, and the variations may be either meaſured by a mark on the whalebone or by an index. This is at preſent the moſt perfect hygrometer, and that which is in moſt general uſe.

In the higher regions of the atmoſphere the cold is found to be intenſe, and yet the moiſture is generally ſaid to be leſs abundant, than in thoſe nearer the ſurface of the earth. This was experienced by all the adventurers in air balloons, as well as by thoſe travellers who have aſcended to the tops of high mountains. It is well known that the ſummits of the alps and other great elevations are uſually covered with ſnow. There is indeed always a certain height of the atmoſphere where water will be found at the freezing point, and this has been called by philoſophers the line of perpetual ſnow. The line, however, varies according to climate and circumſtances. On the peak of Tenerif it commences at the

the height of about two miles and a half, and in England it is generally found at the height of a mile, or a mile and a half. Some botanifts have afferted, that the variation of climate in afcending mountains, was difcernible from the vegetables found upon them, the plants which required a mild temperature, being commonly found near the bottoms, and the hardier, and more northern vegetables towards the fummit.

Different opinions have been entertained concerning the cold in elevated fituations. It was for a confiderable time imagined, that it depended altogether on the rarity of the atmofphere in thofe regions, which is very confiderable; but it has been remarked, on the authority of Count Rumford, that the rarity or denfity of the air appears to have little effect on its conducting power. Some have fuppofed, that as the air is fo much rarer in the upper regions, lefs fire or caloric is required to keep it in a ftate of fluidity, and confequently that there is a real deficiency of that element. The hypothefis of M. Bouguer*, however, comes recommended by its fimplicity, and by its agreement with moft of the other phenomena of heat, and I fhall therefore adopt it with only fome flight variations.

Without entering into the controverfy concerning the identity of fire and light, it is only neceffary to affume as a principle the well known circum-

* Reafons for the cold on the top of the Andes.

ſtance, that the action of light is capable of producing heat in bodies; and the equally well eſtabliſhed fact, that the action of light upon a tranſparent medium, through which it is eaſily tranſmitted, is extremely feeble. This may be proved by the eaſieſt of all poſſible experiments. If highly rectified ſpirits are incloſed in a pure glaſs phial, or any perfectly tranſparent veſſel, the rays of light concentrated by the moſt powerful burning glaſs, will not inflame them; if, however, the ſpirits are placed in a ſpoon, or if that part of the tranſparent veſſel which is not oppoſed to the burning glaſs, is coated with paint or any ſubſtance, which intercepts the rays of light, imbibes or condenſes them, the ſpirits will be inſtantly ſet in a blaze. The earth is therefore the great receptacle of heat, where it is abſorbed and kept as in a ſtore-houſe; but the ſurface of earth which is expoſed to the ſun on the tops of mountains is but very ſmall, and cannot imbibe much of the ſun's heat. The rays from the ſun can indeed only ſtrike the different ſides of the mountain for a ſhort period in every day, and in ſome days, and in ſome parts, not at all. "A horizontal plain alſo when the day is clear, is expoſed at mid day to the perpendicular and undiminiſhed action of the ſun's rays, while they fall obliquely on a plain which is much inclined, or on a pile of rocks." In theſe elevated ſituations, therefore, the majority of the ſun's rays paſs through a tranſparent medium, as through the ſpirits incloſed in a clear glaſs veſſel; and there is no maſs of opake matter to collect or condenſe the heat. The atmoſphere, therefore, in thoſe regions is neceſſarily colder than in thoſe which approach nearer the ſurface of the earth.

The cold in theſe higher regions of the atmoſphere, may be one cauſe why vapours are not collected ſo plentifully there as nearer the earth. The clouds are ſeldom more than a mile in height, and they do not often attain that degree of elevation. From the ſummit of a high mountain, therefore, the proſpect is inexpreſſibly grand. The clouds roll beneath the ſpectator's feet like the vaſt waves of a troubled ocean; and the forked lightnings play between thoſe immenſe maſſes in various directions; while the great body of air in the vallies beneath (clear and tranſparent as it appears to thoſe who inhale it, but in reality charged with vapours) appears like the water of a ſtagnant lake, involving moſt of the objects in total darkneſs, and partially revealing others, which ſeem as if intended to adorn the margin of the flood, and ſerve to enliven and diverſify the ſcene.

Chap. IX.

OF THE WEIGHT, ELASTICITY, AND OTHER GENERAL PROPERTIES OF THE AIR.

General Properties of Air.—Cause of its Elasticity.—Opinions of the Ancients.—Torricellian Experiment.—Barometer.—The Air Pump.—Weight and specific Gravity of Air.—Immense Pressure of the Atmosphere.—Compressibility of Air.—Cupping Glasses.—Effects of the Air's Elasticity.—Air Guns, &c.—Motion of Particles in Bodies.—Nature of the Atmosphere.—Its probable Height.

THE air, considered as a fluid, without any respect to its component principles, has also some properties which are of the utmost importance in the system of nature; and the consideration of these properties will serve to illustrate and explain the nature of all other elastic fluids.

Atmospheric air, considered in itself, is a ponderous, compressible, elastic, transparent body, without colour, invisible, and incondensable by any degree of cold that can be produced in the temperature of this earth. It never becomes the constituent part of any body; though its bases, that is, oxygen and azote, enter into the composition of many.

The FLUIDITY of the air is caused by the matter of fire or heat, which produces in it a degree of elasticity

elaſticity which always tends to dilate the maſs, and which preſerves the motion of its parts. If the air was not elaſtic, it might be formed into a hard body, like ſnow, when its particles are preſſed forcibly together.

It is eaſy to prove that air adheres, with a conſiderable degree of force, to the ſurface of bodies; for when water is put into a veſſel and heated, the ſtratum of air which adheres to the ſides of the veſſel, and which occupies a ſituation between the water and the ſides, ſoon becomes perceptible there in the form of bubbles, in conſequence of the rarefaction which is cauſed by the heat. It becomes ſenſible in the ſame manner in vacuo, in conſequence of the dilation occaſioned by the preſſure being removed *.

The ancients knew air to be a fluid, but their imperfect knowledge of thoſe ſubſtances in general, appears to have diſabled them from uſing thoſe means which the moderns have employed for drawing off and expelling this fluid from a certain ſpace. They were, indeed, utterly unacquainted with the fact, that air is a ponderous fluid. They admitted that there were two kinds of bodies in nature; heavy bodies, ſuch as ſtones, metals, and in general all bodies which, being left to themſelves, had a propenſity to deſcend; and light bodies, ſuch as air, flame, vapours, &c. becauſe theſe bodies appeared to them to aſcend ſpontaneouſly into the upper regions of the atmoſphere. They ſuppoſed, therefore, agreeably

* Briſſon, Tom. ii. p. 93.

to

to this ſentiment, that air was endued with abſolute levity; and that all the effects which the moderns attribute to the principle of gravitation, were to be aſcribed to the *horror* which nature had, according to them, for a *vacuum*. It was, therefore, a long prevailing opinion, that air was deſtitute of weight; and it is not above a hundred and fifty years ſince philoſophers have been convinced of this error. The engineers of the Count de Medici, Great Duke of Florence, having received orders to raiſe ſome water fifty or ſixty feet by means of a common pump, perceived, when they made the attempt, that water would mount only to a certain height, after which it appeared to them, by the void ſpace which they found, that nature was reconciled to a vacuum, or at leaſt ſuffered this defect without thoſe terrible effects which ancient writers had predicted from it. This apparent caprice, on the part of nature, was communicated by the engineers to Galileo, who paid ſome attention to it; though, previous to this accident, he, as well as all others, had ſatisfied himſelf with the common opinion of the *horror* which nature was ſuppoſed to entertain for a *vacuum*. He was at length convinced, by reiterated experiments, that water would riſe only to about thirty-two feet perpendicular in pumps, and that the remainder of the pipe or tube, if it was longer, would be empty. He could then no longer retain the opinion reſpecting the horror of a vacuum, but began to conceive that this horror had its

its limits, and that theſe phenomena might proceed from a phyſical cauſe very different from that to which they had hitherto been attributed. What he had ſuſpected, Toricelli, his diſciple, proved by direct experiment. He firſt made it appear in the year 1645, that a column of air, as it exiſts in the atmoſphere, may be placed in equipoiſe with a column of another fluid, which has the ſame baſe; at length, to avoid the inconvenience of a long pipe, inſtead of water he made uſe of mercury. He took a glaſs tube (Fig. 5.) of two or three inches diameter, hermetically ſealed * at one end, and open at the other; he filled it with pure mercury, and having ſtopped the orifice with his finger, he reverſed the tube, and placed the open end in a veſſel full of the ſame mercury. He had no ſooner removed his finger than the column of mercury, which was about thirty-ſix inches long, was reduced to the length of about twenty-eight inches. Now, if we compare the experiment of Galileo with that of Toricelli, we ſhall find that fluids act in counterpoiſe to each other, exactly in proportion to their reſpective denſities; and that the ſame cauſe (the preſſure of the air) which elevates water to the height of thirty two feet, cannot ſuſtain a column of mercury above the height of twenty-eight or thirty inches.

Paſchal added conſiderably to the proofs of this

* Cloſed by melting the glaſs, and conſolidating it.

doctrine which Torricelli had afforded, and he reasoned in this manner:—If, said he, the air is the cause of this phenomenon, it is because it has ponderance and fluidity; it must press, therefore, in the same manner as liquids, and its pressure must be greater or less according to its height; and every column of whatever fluid is placed in counterpoise with it, will always be longer or shorter in proportion to its density. Hence he proceeded to prove, that a column of air must produce a pressure greater or less, and was capable of sustaining a column of any fluid higher or lower in proportion to its own height, and consequently that a column of water or mercury, at the bottom of a mountain, would rise higher in the Torricellian vacuum than at the summit. M. Paschal next prevailed upon his brother-in-law, M. Perrier, who was at Clermont in Auvergne, to make the following experiment at the base and summit of the mountain, known by the name of *Puy de Dome*.

M. Perrier placed a tube of Torricelli's upon a perpendicular plank (see Fig. 5.) graduated into inches and lines; and having observed to what height the mercury was raised in the tube at the foot of the mountain, he found that it fell gradually in proportion as he ascended towards the summit; and also, on the contrary, that it rose again in the same proportion as he descended: the difference was found to be three inches and one line between the height of the mercury at the summit and the base. This experiment, suggested by *Paschal*, and repeated several

veral times, always produced the ſame reſult; whence it was concluded, that mercury was ſuſtained above its level in the Torricellian tube, by the preſſure of the atmoſphere upon the reſervoir, ſince the mercury in the tube was obſerved to fall, when the column of air which had the reſervoir for its baſe was diminiſhed in height. Theſe experiments, in proving incontrovertibly the weight of air, have authentically reſtored to this fluid a great number of natural properties and effects, which were before attributed to a cauſe merely chimerical.

M. Paſchal afterwards repeated the ſame experiment with water, wine, oil, &c. and the heights of the columns of theſe liquors were always found to be proportional to their denſities; an evident proof that they were counterpoiſed by a weight, which could in thoſe caſes be no other than the preſſure of the air.

Many philoſophers afterwards, having procured *Torricellian* tubes, placed them according to the manner of M. Perrier, upon a ſcale graduated into inches and lines, and by frequent obſervations they perceived, that the height of the mercury in the tube often varied. They concluded, therefore, that the preſſure of the air, which was the cauſe of the ſuſpenſion of the column of mercury, was ſometimes greater and ſometimes leſs, and conſequently that it acted more or leſs forcibly upon the human frame. From theſe cauſes and effects the idea was ſuggeſted, of making from the *Torricellian* tube a new meteorological inſtrument, the ſame which is now

now commonly known by the name of a *barometer* *.

Air acts upon barometers in two modes, by its weight and by its elasticity. The variation, therefore, of the pressure upon the reservoir is produced by two causes, by the variation in the weight of the

* "To fill a barometer tube, (says Mr. Adams) I take a clean glass tube about thirty-three inches long, and pour quicksilver into it by means of a small paper funnel; you observe, that as the quicksilver rises in the tube, there are bubbles of air left behind in several parts; I continue pouring the quicksilver till it fills the tube within about half an inch of the top. I then apply my finger hard and close upon the top of the tube, and invert it; by which means the air that was on the top, now rising through all the quicksilver, gathers every bubble in its way. I revert the tube or turn it up again, and the bubble of air reascends, and if there are any small bubbles left, carries them away; if, however, any remain, the operation must be repeated. I now fill the tube to the top, and placing my finger on the open end of the tube, plunge that end into this bason of quicksilver; when the end of the tube is perfectly submerged in the quicksilver, I take my finger away, and you see the quicksilver remains suspended in the tube, leaving a vacuum at top. The column of quicksilver is about thirty inches in height; now you will observe that there can be no air in the space between the quicksilver and the top of the tube, for till the finger that closed the orifice in the bason was taken away, that space was filled with quicksilver, and the quicksilver, which was thirty-three inches high, sunk in the tube, and left that space free from air, for no air could get into the tube, unless it could force its way through the quicksilver in the bason, and the thirty inches in the tube; or penetrate through the sealed end of the tube: but as neither of those can be done, it follows, that in the part of the tube which the quicksilver leaves, there must be a vacuum." *Adams's Lectures.* Vol. i, p. 32.

by

incumbent air, and by that of its elasticity. The weight of air varies according to its density, and its intermixture with other substances which are soluble by it; its elasticity varies according to its density, and the quantity of heat with which it is charged. The greater part of foreign substances which intermix with air only, under the form of elastic fluids, diminish the weight of the column of air, because they are lighter than it; but those substances which are soluble in air augment its density, and consequently its weight, in the same manner that salt dissolved in water increases its weight and density.

The barometer has, therefore, another property, not less useful to philosophers than that which has been already mentioned. It points out the changes of the weather, especially when they are likely to be considerable.

From the numerous observations and experiments, which have been made from time to time upon barometers, the seven following propositions have been established by M. Brisson. "First, That the mean height of mercury in France is twenty-seven French inches and an half. Secondly, That the variations from this height seldom exceed three inches, that is, that its least elevation is twenty-six inches, and its greatest twenty-nine. Thirdly, That these variations become less towards the equator, and greater in the northern climates. Fourthly, That when the mercury falls in the barometer it announces rain or wind, or in general what is called bad weather. Fifthly, On the contrary, when

the

the mercury riſes it announces fine weather. Sixthly, That theſe predictions fail ſometimes, eſpecially if the variations in the height of the mercury are very ſlow and inconſiderable. Seventhly, That the predictions are almoſt infallible, when the mercury aſcends or deſcends conſiderably in a ſhort time; as for example, about one-third of an inch (or three or four lines) in the courſe of a few hours *.

Thus in relating the diſcovery of the barometer, we have ſeen that philoſophers were convinced that an actual vacuum might be formed. The air pump, however, was not diſcovered till 1654. For the firſt invention of this, the world is indebted to Otto Gueric, a German; but it was our countryman Boyle who converted it to real uſes, it was he who improved it, and applied it to philoſophical purpoſes. In the hands of Gueric it was a mechanical inſtrument; in thoſe of Boyle it was a truly philoſophical machine. By this machine we can with eaſe empty a glaſs veſſel of its air, and put what bodies into it we think fit. Thus comparing the changes wrought upon bodies by being kept from air, with the ſame bodies when expoſed to air, we come to a knowledge of the effects of air upon bodies in general.

As the air-pump is a machine very generally known, I ſhall not attempt a new deſcription of it; but for the ſake of thoſe readers who are

* Briſſon. Vol. i.

but

but little acquainted with philosophical apparatus, take the description of it from one of the most popular writers on these subjects, in order that its construction may be the more easily understood.

Having put a wet leather on the plate L L (see Plate XX. Fig. 1.) place the large glass vessel or receiver M with its mouth downwards upon the leather, so that the hole *i* in the plate may be within the glass. Then turning the handle F backward and forward, the air will be pumped out of the receiver by the contrivance of the mechanism below. As the handle F, represented more at large (Fig. 2.) is turned backwards, it raises the sucker or piston *d e* in the hollow barrel B K by means of the toothed wheel E engraining in the toothed rack D *d*: and as the piston or sucker is leathered so tight as to fit the barrel exactly, no air can get between this piston and the barrel, and therefore all the air above *d* in the barrel is lifted up towards B, and a vacuum made in the barrel from *e* to *b*: upon which part of the air in the glass M (Fig. 1.) by its spring rushes through the hole *i* in the brass plate L L along the pipe G G, which communicates with both barrels by the hollow trunk I H K, and pushing up the valve *b* (a valve is a bit of leather that covers a hole as the flapper of a bellows, admitting the air in, but suffering none to go back) the air then raising the valve enters into the vacuity *b e* of the barrel B K. For the air will naturally press into those places where it is least resisted. All this is done by drawing the handle towards D.—Next turning the handle forward the contrary way towards C, the piſton *d e* is depreſſed in the barrel, and as the air which had got into the barrel cannot be puſhed back through the valve *b*, for the valve cloſes like the flapper of a bellows, and will not let the air back the way it came, the air muſt therefore aſcend through an hole in the piſton, and eſcapes through a valve at *d*; and is hindered by that valve from returning into the barrel when the piſton is again raiſed. At the next raiſing of the piſton, a vacuum is again made in the ſame manner as before, between *b* and *e*, upon which more of the air which was left in the glaſs receiver M gets out thence, and runs into the more empty barrel B K through the valve *b*. The ſame thing is effected with regard to the other barrel A I, and as the handle F is turned backwards and forwards, it alternately raiſes and depreſſes the piſtons in their barrels, always raiſing one while it depreſſes the other. And as there is a vacuum made in each barrel when its piſton is raiſed, every particle of air in the receiver M puſhes out another through the hole *i* and pipe G G into the barrels, until at laſt the air in the glaſs receiver comes to be ſo much rarefied that it can no longer get through the valves, and then no more can be taken out of the receiver. From which it appears, there is no ſuch thing as making a perfect vacuum in the receiver; for the air that leaves the receiver is driven out by that which remains behind, and there muſt therefore ſome portion remain behind at laſt.

This

This is the conſtruction and nature of the air-pump. Some inſtruments at firſt contrived only for explaining ſcience, become at laſt, by frequent uſe, a part of the ſcience itſelf, and demand an equal explanation. Such is the caſe with this; and the reader muſt pardon ſome prolixity in the deſcription. There is a cock *k* below the plate L L, which being turned lets air into the receiver again. There is a glaſs tube *l m n* open at both ends, and about thirty-four inches long, the upper end communicating with the hole in the pump plate, and the lower end immerſed in quickſilver at *n* in the veſſel N. To this tube is fitted a wooden ruler *m m*, divided into inches and parts of an inch from the bottom at *n*, where it is upon a level with the ſurface of the quickſilver; and continued up to the top, a little below *l*, to thirty or thirty-one inches. Now the quickſilver in this tube riſes as the air is exhauſted in the receiver, for it opens into the receiver through the plate L L. And the more the air is exhauſted, the more will the quickſilver riſe, ſo that by this means the quantity of air pumped out of the receiver may be very exactly meaſured *.

From all the preceding facts, and eſpecially from the experiment of Torricelli, it appears, that air is a PONDEROUS fluid; in other words, that it poſſeſſes gravity, and its weight may be eaſily aſcertained.

From a large phial (or rather from a flaſk, or any glaſs veſſel of a globular form, for reaſons that

* Goldſmith's Philoſophy, vol. ii. p. 56.

 will

will afterwards appear) to the neck of which is annexed a ſtop-cock, the air may be exhauſted either by means of the air-pump, or by filling the flaſk with mercury, and emptying it gradually in a veſſel containing a quantity of that fluid, and turning the cock before the neck is entirely extricated, which produces a more perfect vacuum than that made by the air-pump. The veſſel thus emptied of its air may be weighed by a nice balance; and this done, re-admit the air by turning the cock, when it will ruſh in with conſiderable violence; and though the flaſk was balanced before, it will now become heavier, and preponderate. The air contained in a quart flaſk will by this experiment be found to weigh about fourteen grains and a half.

To find the ſpecific gravity of the air, the flaſk muſt be filled with pure water, and again weighed. The weight of a cubic foot of pure diſtilled water is about 1,000 ounces avoirdupois, and of a cubic inch 253 grains and not quite one-fifth *. Dividing the weight of the water contained in the flaſk, therefore, by this number of grains, will give the number of its cubic inches; and as this furniſhes us with the number of cubic inches of air as well as of water, their relative gravity is eaſily known. By ſeveral very accurate experiments, Mr. Haukſbee fixed the ſpecific gravity of air to that of water to be in proportion as 1 to 885.

* 253.18 grains. Decimal arithmetic ſhould always be employed in philoſophical calculations, for the ſake of accuracy.

By

By means of its gravity, the atmoſphere preſſes with great force upon all bodies, according to the extent of their ſurface. According to M. Paſcal, the quantity of this preſſure is not leſs than 2232 pounds upon every ſquare foot of ſurface, or upwards of fifteen pounds upon every ſquare inch. Computing, therefore, the ſurface of a man's body at 15 ſquare feet, the whole preſſure, which each perſon ſuſtains, will be nearly equal to 33,480 pounds. By this enormous preſſure we ſhould undoubtedly be cruſhed in a moment, if every part of our body was not filled with air, or ſome other elaſtic fluid, the ſpring of which is ſufficient to counteract the preſſure.—" We are fearfully and " wonderfully made!"

The whole quantity of preſſure upon the earth muſt thus be immenſe, and has been computed equal to that of a globe of lead of ſixty miles in diameter.

It is the gravity of the air which cauſes that ſtrong preſſure upon the hand, when it is placed upon the mouth of a receiver open at the top, in which a vacuum has been made by an air pump; for as ſoon as the air in the receiver has been rarefied by the action of the machine, it is no longer capable of ſuſtaining the exterior preſſure of the air, as it would have been if its denſity had not been altered. It is, therefore, the preponderance of the weight of the exterior air, which preſſes the hand with ſuch force to the edges of the receiver; and this preſſure is according to the ſize of the aperture of the receiver, becaufe the column of air is enlarged in proportion to the diameter of the aperture.

Our furprife is excited by obferving, that notwithftanding this great preffure upon a glafs receiver, when a vacuum is obtained, the glafs is not dafhed to pieces as might be expected. Its prefervation is in a great meafure owing to the rotundity of its figure, and to the excefs of the exterior furface over the interior; for the fubftance which compofes the body of the veffel refembles, in this cafe, the fubftance which compofes an arch in a bridge. We may be convinced of the truth of this obfervation by taking a receiver of another form, that is open at both ends, and covered with a bladder at the top, and beginning to exhauft the air, when the bladder will infallibly be burft by the preffure of the exterior atmofpheric air.

This gravity of the atmofphere accomplifhes many ufeful purpofes in nature, fuch as preventing the blood veffels of animals, and the fap veffels of plants, from being too much diftended by the expanfive power, which has a perpetual tendency to fwell them out. On this account we fee, that in the operation of cupping, where the preffure of the air is taken off from a particular part, the expanfive force inftantly acts, and fwells out the veffels to a great degree. This is alfo the reafon why the bodies of animals fwell when they are put into an air pump. It is owing to the gravity of air that fubftances remain liquid, which would become aeriform in

vacuo.

vacuo. Salts and oils remain united in air, but ſeparate as ſoon as that fluid is extracted. When hot water is put under an exhauſted receiver, it boils violently; becauſe the preſſure of the air being now taken off, there is nothing to prevent it from aſſuming the ſtate of vapour.

'This preſſure of the atmoſphere,' ſays Lavoiſier, 'cauſes water to remain in a liquid ſtate till it is raiſed to 212° of Fahrenheit's thermometer, the quantity of heat which it receives in a lower temperature being inſufficient to overcome the preſſure of the atmoſphere. Whence it appears, that without this preſſure we ſhould not have any permanent liquid, and ſhould only be able to ſee bodies in that ſtate of exiſtence in the very inſtant of melting, as the ſmalleſt additional heat would inſtantly ſeparate their particles, and diſſipate them through the ſurrounding medium. Beſides, without this atmoſpheric preſſure, we ſhould not even have any aeriform fluids, ſtrictly ſpeaking, becauſe the moment the force of attraction is overcome by the repulſive power of the heat, the particles would ſeparate themſelves indefinitely, having nothing to limit their expanſion, unleſs their own gravity might collect them together, ſo as to form an atmoſphere*.'

Air, being an elaſtic fluid, is conſequently COMPRESSIBLE, as the very word implies; the weight, therefore, of the atmoſphere compreſſes its lower parts, for in low vallies it is more compreſſed, and

* Lavoiſier's Elem. of Chemiſt. p. 8.

has more densfity than upon high mountains; but this is not the case with water, which not being elastic in its ordinary state, is hardly compressible at all; so that the different portions of the same mass of water have nearly the same density throughout its whole depth.

M. Amontons contends, that there is no fixing any bounds to the condensation of air. Dr. Halley has asserted, in the Philosophical Transactions, that, from the experiments made at London and Florence, it might be safely concluded, that no force whatever is able to reduce air into 800 times less space than that which it naturally possesses on the surface of our earth.

It has been proved by various experiments, that a column of compressed air is diminished in proportion to the augmentation of the pressure by which it is condensed.

The simplest of these experiments is, to pour a quantity of quicksilver into the tube A B C (Plate XIX. Fig. 6.) closed at A, and open at C. When the tube is filled with quicksilver to E, then the air inclosed in the leg A B, will prevent its rising higher than D, and the column D B will be in equilibrio with F B; consequently the quicksilver contained between F D will not at all press on the air between A and D; but the column E F, acting with its whole weight on the quicksilver between F and D, causes it to press on the air at D, and condense it. By increasing the quantity of quicksilver the condensation is increased; and it is found, that

that the ſpaces into which the air is condenſed by different weights are inverſely as thoſe weights, or its denſity is as the preſſure it bears.

It is however, very probable, after all, that this compreſſion does not take place in an extreme degree, for we know of no body which can be compreſſed ad infinitum.

From all that has been ſtated, and particularly from the experiment of Torricelli, it will be evident, that the common notion of ſuction is a vulgar error; and that when a fluid ruſhes ſpontaneouſly into a given ſpace, it is in conſequence of the air being expelled, or made thinner in that ſpace, than in that which is contiguous to it, when the preſſure of the atmoſphere acts upon the fluid, and forces it to occupy the ſpace from which the air is either entirely or partially expelled. This is the principle on which the common pump is conſtructed; for a vacuum being made in the tube by the riſing of the piſton, the weight of the atmoſphere preſſes upon the circumadjacent water, and forces it up into the body of the pump: but this engine will be more particularly deſcribed in treating of hydraulics.

The elaſticity of the air is now generally ſuppoſed to depend upon the latent heat or fire, which retains it in its fluid form. If we take a bladder well cloſed at the neck, and containing but a ſmall quantity of air; while this bladder is expoſed to the preſſure of the atmoſphere it will remain in its primitive ſtate, as when the ſmall quantity of air was admitted; but if it is placed under the re-

 ceiver

ceiver of an air pump, and the machine set in motion to exhaust the air surrounding the bladder, it will begin to open and swell, and that in proportion to the diminution of the density of the air in the receiver *.

Philosophers have doubted whether this elastic power of the air is capable of being destroyed or diminished. Mr. Boyle endeavoured to discover how long air would retain its spring after having assumed the greatest degree of expansion his air pump could give it; but he never observed any sensible diminution. Desaguliers says, that air, which had been inclosed half a year in a wind gun, had lost none of its elasticity; and Roberval asserts, that he has preserved air in the same manner for sixteen years; and that after that period he observed, that its expansive projectile force was the same as if it had been newly condensed. Dr. Hales and Mr. Hauksbee on the contrary conclude, from other experiments, that the elasticity of the air is capable of being impaired and diminished by a variety of causes.

M. Lavoisier, however, has solved these difficulties, by proving, that the elasticity of all gasses or elastic fluids depends upon that of caloric, which seems to be the most eminently elastic body in nature. Nothing, says he, is more readily conceived, than that one body should become elastic by entering into combination with another body possessed of that quality. ' We must allow that this is only an explanation of elasticity, by an assumption of

* Brisson, tom. ii. p. 103.

elasticity;

elaſticity; and that we thus only remove the difficulty one ſtep farther; and that the nature of elaſticity, and the reaſon for caloric being elaſtic, remain ſtill unexplained *.'

On the elaſticity and compreſſibility of air depend the ſtructure and uſes of the air gun. In theſe inſtruments a quantity of air is condenſed by various contrivances, in ſuch a manner that the condenſing force being removed, a bullet will be ſent to a conſiderable diſtance with little or no noiſe, but with great force. ' The common air gun is made of braſs, and has two barrels. The middle barrel K A (ſee Plate XX. Fig. 3.) from which the bullets are ſhot, and the larger outſide barrel, cloſed up at the end C D, and in this the air is driven and kept condenſed, by means of a ſyringe M, which drives the air in, but ſuffers none to go back. This ſyringe having been worked for ſome time, the air is accumulated in great quantities in the external barrel, and this air may be made to ſtrike upon the ball K by means of the trigger O, which pulls back the ſpiral R, and this ſpiral opens a valve behind the ball. When the valve is open, the air condenſed in the outward barrel ruſhes in behind the ball, and drives it out with great violence, ſo great, that at twenty-ſix yards diſtance it would drive through an oak board half an inch thick. If the valve behind K is ſhut ſuddenly, one charge of condenſed air may make ſeveral diſcharges of bullets. The little pellet guns, in the hands of children, ſhew alſo the force and ſpring of the air; for one

* Elem. of Chem. p. 22.

pellet ſtopping the mouth of the gun at one end, and another being driven in at the oppoſite end, the air contained in the bore of the gun between each pellet is continually condenſing, as the hinder pellet is driven towards the foremoſt, till at laſt the ſpring becomes ſo great as to drive the foremoſt pellet forward with ſome noiſe and violence. In the large air-gun, however, the noiſe is by no means ſo great: upon its diſcharge nothing is heard but a ſort of a ruſhing wind; and it is very poſſible, that what we are vulgarly told of ſome men killing others by loading their piſtols with dumb powder, might have proceeded from the ſilent effects of the air-gun *.'

The air gun deſcribed by the author from whom the above is quoted has been in a great meaſure ſuperſeded by one of a more ſimple conſtruction, originally invented by the late ingenious Benjamin Martin. It is formed like a common gun, with a ſingle barrel, and the condenſed air is contained in a braſs ball, which ſcrews on below the lock. The ball is charged with a ſtrong ſyringe, and is furniſhed with a ſtop cock, and ſcrews on the end of the ſyringe to be charged, and then, when the cock is turned, it may be ſcrewed on to the gun. The bullet is made to fit the barrel very exactly, and is rammed in as the ball of a muſket. Each gun is generally furniſhed with two braſs balls, which will contain ſufficient air for about twenty diſcharges; and that which is not in preſent uſe may be carried

* Goldſmith's Philoſophy, Vol. II. p. 96.

in

in the pocket. The gun is charged by turning the cock, which fills a ſmall chamber at the butt end of the barrel with condenſed air, when the cock may be turned again to ſave the reſt for further diſcharges. The pulling of the trigger opens a valve, and the ſpring of the air forces out the bullet, as in the inſtrument already deſcribed.

The elaſticity of the air produces alſo conſiderable effects in the natural world; for by inſinuating itſelf into the pores of bodies, and poſſeſſing this power of expanding, which is ſo eaſily excited, it muſt neceſſarily put the particles of bodies into which it inſinuates itſelf into a ſtate of almoſt perpetual oſcillation. The truth of this obſervation is evinced particularly in the air veſſels of plants, which perform the office of lungs; for the contained air, expanding and contracting alternately, according to the increaſe or decreaſe of the heat, preſſes the veſſels, and eaſes them again alternately, thus keeping up a continual circulation in the fluids. Even entire columns of marble have been known to cleave, from the increaſed elaſticity of ſome ſmall bubbles of air contained in them.

Putrefaction and fermentation are proceſſes depending entirely on the action of the air; for we know by numerous experiments, that neither of theſe changes will take place in vacuo, even in ſubjects the moſt favourably diſpoſed to them.

In ſpeaking of the terreſtrial atmoſphere it has been intimated, that it is found to be nearly the ſame as to compoſition in all climates and in all places, as well upon

upon the tops of high mountains as in the vallies below, but that it is considerably less dense in proportion to the height. The whole globe of the earth is entirely enveloped with it; the whole atmosphere is carried along with the terrestrial orb, both in its diurnal and annual motion, and is a principal operator in the mechanism of nature.

Various means have been devised for ascertaining the height of the atmosphere. 'These attempts,' says Mr. Adams, 'commenced soon after it was discovered, by means of the Torricellian tube, that air is a gravitating substance. Thus it also became known that a column of air, whose base is a square inch, and the height that of the whole atmosphere, weighs fifteen pounds; and that the weight of air is to that of mercury, as 1 to 10,800: whence it follows, that if the weight of the atmosphere is sufficient to raise a column of mercury to the height of thirty inches, the height of the aerial column must be ten thousand eight hundred times as much, and consequently a little more than five miles high.

'It was not, however, at any time supposed, that this calculation could be just; for as the air is an elastic fluid, the upper parts must expand to an immense bulk, and thus render the calculation above related exceedingly erroneous. By experiments made in different countries, it has been found that the spaces, which any portion of air takes up, are reciprocally proportional to the weight with which it is compressed. Allowances were therefore to be

made

made in calculating the height of the atmoſphere. If we ſuppoſe the height of the whole divided into innumerable equal parts, the denſity of each of which is as its quantity, and the weight of the whole incumbent atmoſphere being alſo as its quantity, it is evident, that the weight of the incumbent air is every where as the quantity contained in the ſubjacent part, which makes a difference between the weights of each two contiguous parts of air. By a theorem in geometry, where the differences of magnitudes are geometrically proportional to the magnitudes themſelves, it appears that theſe magnitudes are in continual arithmetical proportion; therefore if, according to the ſuppoſition, the altitudes of the air, by the addition of new parts into which it is divided, do continually increaſe in arithmetical proportion, its denſity will be diminiſhed, or (which is the ſame thing) its gravity decreaſed in continual geometrical proportion.

'It is now eaſy, from ſuch a ſeries, by making two or three barometrical obſervations, and determining the denſity of the atmoſphere at two or three different ſtations, to determine its abſolute height, or its rarity at any aſſignable height. Calculations accordingly were made upon this plan; but it having been found that the barometrical obſervations by no means correſponded with the denſity which, by other experiments, the air ought to have had, it was ſuſpected that the upper parts of the atmoſpherical regions were not ſubject to the ſame laws with the lower ones. Philoſophers, therefore, had recourſe to another method for determining the altitude of the atmoſphere, viz. by a calculation of the height from which the light of the ſun is refracted, ſo as to become viſible to us before he himſelf is ſeen in the heavens. By this method it was determined, that at the height of forty-five miles the atmoſphere had no power of refraction; and conſequently beyond that diſtance was either a mere vacuum, or the next thing to it, and not to be regarded.

'This theory ſoon became very generally received, and the height of the atmoſphere was ſpoken of as familiarly as the height of a mountain, and reckoned to be as well aſcertained, if not more ſo, than the heights of moſt mountains are. Very great objections, however, which have never yet been removed, ariſe from the appearances of ſome meteors, like large globes of fire, not unfrequently to be ſeen at vaſt heights above the earth. A very remarkable one of this kind was obſerved by Dr. Halley in the month of March 1719, whoſe altitude he computed to have been between ſixty-nine and ſeventy-three and a half Engliſh miles; its diameter two thouſand eight hundred yards, or upwards of a mile and a half, and its velocity about three hundred and fifty miles in a minute. Others, apparently of the ſame kind, but whoſe altitude and velocity were ſtill greater, have been obſerved, particularly that very remarkable one, Auguſt 18th, 1783, whoſe diſtance from the earth could not be

leſs

leſs than ninety miles, and its diameter not leſs than the former, at the ſame time that its velocity was certainly not leſs than one thouſand miles in a minute. Fire-balls, in appearance ſimilar to theſe, though vaſtly inferior in ſize, have been ſometimes obſerved at the ſurface of the earth. Of this kind, one was ſeen on board the Montague, 4th November, 1749, which appeared as big as a large millſtone; it broke with a violent exploſion.

'From analogical reaſoning, it ſeems very probable that the meteors, which appear at ſuch great heights in the air, are not eſſentially different from thoſe which, like the fire-ball juſt mentioned, are met with on the ſurface of the earth. The perplexing circumſtances with regard to the former are, that at the great heights above-mentioned, the atmoſphere *ought not to have any denſity ſufficient to ſupport flame, or to propagate ſound*; yet theſe meteors are commonly ſucceeded by one or more exploſions, nay, are ſometimes ſaid to be accompanied with a hiſſing noiſe as they paſs over our heads. The meteor of 1719 was not only very bright, inſomuch that for a ſhort ſpace it turned night into day, but was attended with an exploſion, heard over all the iſland of Britain, occaſioning a violent concuſſion in the atmoſphere, and ſeeming to ſhake the earth itſelf. That of 1783 alſo, though much higher than the former, was ſucceeded by exploſions; and, according to the teſtimony of ſeveral people, a hiſſing noiſe was heard as it paſſed. Dr. Halley acknowledged, that he was unable to reconcile theſe cir-

 cumſtances,

cumftances with the received theory of the height of the atmofphere; as, in the regions in which this meteor moved, the air ought to have been three hundred thoufand times more rare than what we breathe, and the next thing to a perfect vacuum.

'In the meteor of 1783, the difficulty is ftill greater, as it appears to have been twenty miles farther up in the air. Dr. Halley offers a conjecture, indeed, that the vaft magnitude of fuch bodies might compenfate for the thinnefs of the medium in which they moved; whether or not this was the cafe, cannot indeed be afcertained, as we have fo few data to go upon; but the greateft difficulty is to account for the brightnefs of the light. Appearances of this kind are, indeed, with great probability, attributed to electricity, but the difficulty is not thus removed; though the electrical fire pervades with great eafe the vacuum of a common air-pump, yet it does not in that cafe appear in bright well defined fparks as in the open air, but rather in long ftreams refembling the aurora borealis. From fome late experiments, Mr. Morgan concludes that the electrical fluid cannot penetrate a perfect vacuum. If this fhould be the cafe, it fhews that the regions we fpeak of are not fuch a perfect vacuum as can be artificially made; but whether they are or not, the extreme brightnefs of the light fhews that a fluid was prefent in thofe regions, capable of confining and condenfing the electric matter as much as the air does at the furface of the ground; for the brightnefs of thefe meteors, considering their distance, cannot be supposed inferior to that of the brightest flashes of lightning.

'It appears, therefore, that the absolute height of the atmosphere is not yet determined. The beginning and ending of twilight, indeed, shew, that the height at which the atmosphere begins to refract the sun's light is about forty-four or forty-five English miles. But this may, not improbably, be only the height to which the aqueous vapours are carried; for it cannot be thought any unreasonable supposition, that light is refracted only by means of the aqueous vapour contained in the atmosphere: and where this ceases, it is still capable of supporting the electric fire at least as bright and strong as at the surface. That it does extend much higher, is evident from the meteors already mentioned; for all these are undoubtedly carried along with the atmosphere; otherwise that of 1783, which was seen for about a minute, must have been left one thousand miles to the westward, by the earth flying out below it in it's annual course round the sun *.'

* Adams's Lectures, vol. i. p. 52.

CHAP. X.

OF SOUND.

Sound confidered in Three Points of View.—Caufed by a Vibration in the Parts of Bodies.—Propagated by an undulatory Motion of the Air.—This proved by Experiment.—Glaffes broken by an Effort of the Voice.—Elaftic Fluids not the only Means of tranfmitting Sound.—Water or folid Bodies convey it.—Velocity of Sound.—Experiments on this Subject.—Echoes.—Whifpering Gallery.

THERE is another property of air, which could not fo conveniently be introduced into the preceding chapter; I mean the power of tranfmitting founds.

Sound is produced by a vibrating motion, excited in a fonorous body by a blow or a fhock from another body, and the fame motion is communicated by this fonorous body to the fluid which furrounds it, and tranfmitted by this fluid to the ear, which is an organ admirably adapted to receive its impreffion.

From this definition it follows, that found fhould be confidered in three different views; firft, with refpect to the fonorous body which produces it; fecondly, as to the medium which tranfmits it; and, thirdly, as to the organ which receives the impreffion.

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Thoſe bodies are properly called *ſonorous* which afford a ſound diſtinct, and of ſome duration, ſuch as bells, the ſtrings of a violin, &c. and not thoſe which cauſe only a confuſed noiſe, ſuch as a ſtone produces when it falls upon a pavement. When bodies are, ſtrictly ſpeaking, ſonorous, they are neceſſarily elaſtic, as will be afterwards proved; and their ſound, as to its force and duration, is proportionate to their vibrations.

Suppoſe, for example, the bell of a clock to be ſtruck by any ſolid body, a kind of undulating or tremulous motion is imparted to the minute particles; and this motion may be even perceived by the hand or fingers when applied to the bell.

To underſtand this more completely, let us conceive that a bell is compoſed of a ſeries of circular zones, decreaſing in diameter all the way to its top, each of which may be conſidered as a flat ring, compoſed of as many concentric circles as its thickneſs will admit of. If this ring is ſtruck at the point *a* (Plate XX. Fig. 4.) the part ſo ſtruck tends towards *g*, and at the ſame time the parts *b* and *d* tend towards *i* and *m*, and this action in theſe parts neceſſarily cauſes the point *c* to approach towards *e*; by their elaſtic power, however, theſe parts preſently regain the poſition in which they were before the bell was ſtruck; but as they return with an accelerated force, they generally go beyond the point where they ought to reſt. The part *a*, therefore, after having returned from *g* to *a*, tends towards *f*, the part *c* towards *h*, and the parts *b*

 and

and *d* towards *k* and *l*; whence it happens that the bell, at firſt of a circular form, really becomes alternately oval in two different directions; it follows then, that in thoſe parts where the curvature is the greateſt, their exterior points depart from each other.

The ſame circumſtance happens to the muſical cord of a harp, or other ſtringed inſtrument, when it is touched; for, in order to become angular, as B C D or B E D (Fig. 5.) it is neceſſary that the ſtring ſhould be ſtretched or lengthened, and conſequently its particles be in ſome meaſure removed from the point of contact.

There are then two vibrations which take place in ſonorous bodies; the general vibration, which changes the form of the body, and the particular vibration, which affects the minute particles, in conſequence of the former. M. de la Hire has proved *, that the ſound is not owing to the general vibration, but rather to the vibration of the particles; for whenever the two vibrations can be ſeparated, it is found that the former produces no ſound; but when the general vibration is accompanied with a vibration of the particles, the latter it is that regulates the duration, the force, and the modulation of the ſound: if, on the contrary, theſe vibrations are ſtopped or interrupted by touching the ſonorous body, the ſound immediately ceaſes. On this account clock-makers attach to the hammer, which

* Mem. de l'Acad. 1716, p. 264.

ſtrikes

Fig. 3.

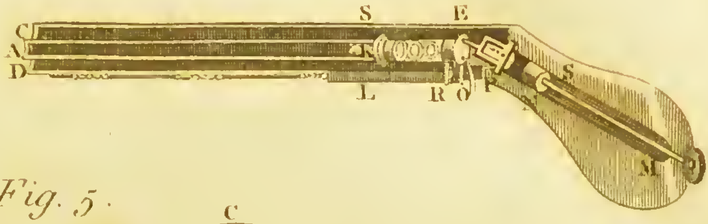


Fig. 5.

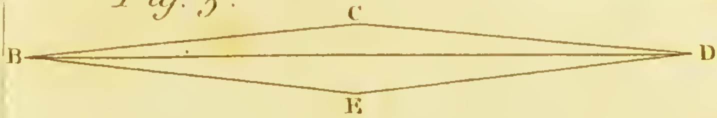


Fig. 4.

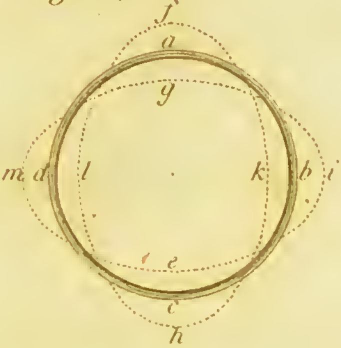


Fig. 1.

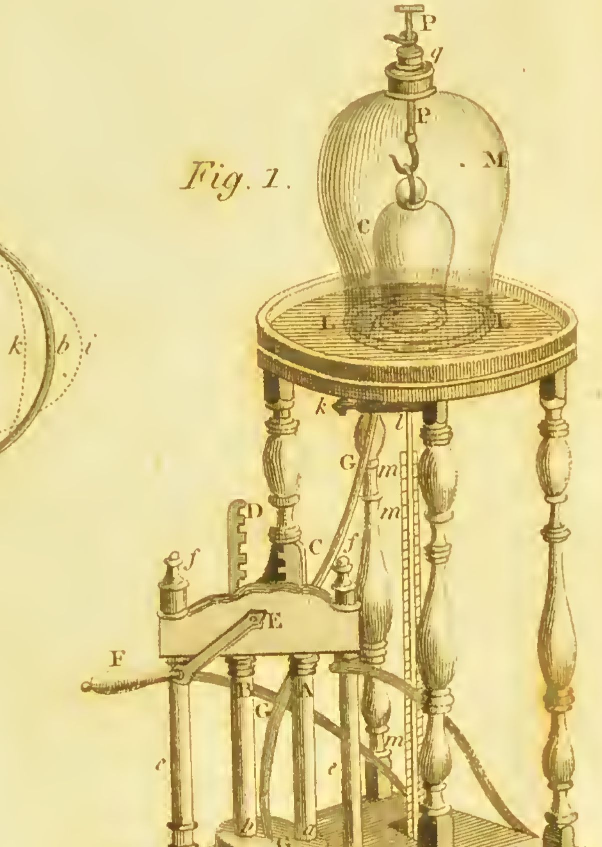
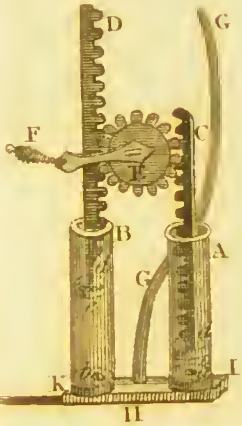


Fig. 2.



ſtrikes the bell of the clock, a ſmall ſpring, which elevates it again the moment it has ſtruck, and prevents it from remaining upon the bell, which would conſiderably deaden or deſtroy the ſound.

Acute ſounds are produced, when the vibrations of the ſounding body are more frequent; grave or deep ſounds, when they are leſs ſo: no medium between acute and grave ſounds can be found. Sonorous bodies are ſaid to be in uniſon when they vibrate with the ſame frequency; when one vibrates twice as faſt as the other, they differ by an octave; and other ratios, with reſpect to the quickneſs of vibration, are diſtinguiſhed by other names. Cords, which are ſhort and tightly ſtretched, produce acute ſounds; thoſe which are long and lax, grave ſounds.

The motion or vibration of bodies at a diſtance from us would not affect our ſenſe of hearing without the medium of ſome other body, which receives an impulſe from this motion, and communicates the vibrations to our organs. Thus a hard blow upon an anvil or upon a bell could not be heard by us, even at a very ſmall diſtance, if there was not a medium between thoſe objects and us capable of tranſmitting the vibrations to our auditory nerves. Elaſtic fluids are the moſt effective mediums for this purpoſe, and conſequently the air is the moſt common vehicle of ſound, which is very eaſily proved by ringing a bell under the receiver of an air-pump, the ſound it affords being found gradually to diminiſh as the air becomes exhauſted, till at length it ceaſes to be heard at all. That the air is capable of being agitated with great force appears from the violent concussions produced by explosions of gunpowder, as well as from the power, which some persons are known to possess, of breaking drinking-glasses by means of their voice, when sounded in unison with the note which the glass would have produced when struck. The tremulous motion excited in the air by sounding bodies has been supposed analogous to the successive rings which are produced by disturbing the surface of water. This hypothesis, however, was disproved by the observation that sounds, whether weak or loud, always travel with the same velocity, which does not hold true with respect to the rings on the surface of water, since these move faster or slower according to the force of the cause which excited them.

Every sound is rendered stronger or weaker, and may be heard at a greater or less distance, according to the density * or rarity of that elastic fluid, by which it is propagated. According to Mr. Hauksbee, who has made deep researches into this branch of philosophy, when air has acquired twice its common density it transmits sound twice as far as common air; whence he reasonably concludes, that sound increases, not only in direct proportion

* That some degree of density is necessary in a fluid, to enable it to convey sounds, is evident from this fact, that light, which is a fluid extremely rare, is totally destitute of this power.—*Traite Elem. de Physique*, tom. ii. p. 162.

to the denſity of the air, but in proportion to the ſquare of this denſity.

If ſound was propagated in an elaſtic fluid more denſe than the air, it would be carried proportionably farther. I have proved this, ſays M. Briſſon *, by putting a ſonorous body into carbonic acid gas or fixable air, the denſity of which is about one-third more than that of atmoſpherical air; the conſequence was, that at that time, and in that ſituation, the ſound was very conſiderably increaſed. For the ſame reaſon, the dryneſs of the air, which increaſes its denſity, has a conſiderable effect in rendering ſound louder and more audible. Sound is alſo much increaſed by the reverberation of the pulſes of the air from thoſe ſurrounding bodies againſt which they ſtrike, whence it happens that muſic is ſo much louder in a cloſe apartment than in the open air.

Elaſtic fluids are, however, not the only mediums through which ſound may be tranſmitted; for it may be propagated by means of water and other liquors, which may be proved by immerſing a ſonorous body in water; but it muſt be obſerved, that in this caſe the ſound will be leſs perceptible, and will not extend to ſo great a diſtance; the cauſe of this diminution is, becauſe mediums for the tranſmiſſion of ſound ſhould be elaſtic, and that is a property which water and other liquors poſſeſs only in a very reſtricted degree.

* Elem. de Phyſique, tom. ii. p. 164.

Sound

Sound is alſo tranſmitted by ſolid bodies, provided they poſſeſs a ſufficient degree of elaſticity to produce this effect.

Light, we have already ſeen, is projected or reflected with incredible velocity; but ſound is tranſmitted much more ſlowly, and its progreſſion is very perceptible to our ſenſes. The flaſh from a cannon, or even a muſket, may be ſeen ſome ſeconds before the ſound reaches our ears. As the motion of light, therefore, is inſtantaneous with reſpect to any moderate diſtance, this has been the common means employed for aſcertaining the progreſs of ſound. Sir Iſaac Newton obſerves, that "all ſounding bodies propagate their motions on all ſides by ſucceſſive condenſations and relaxations; that is, by an alternate progreſſion and return of the particles;" and theſe vibrations, when communicated to the air, are termed pulſes of ſound.

All pulſes move equally faſt. This is proved by experiment; and it is found that they paſs about one thouſand one hundred and forty-two feet in a ſecond, whether the ſound is loud or low, grave or acute *.

Some

* That we labour under a deception with regard to tones, and that they become higher as they come from a greater diſtance, may be inferred from muſical compoſition. The greateſt maſters in this art, when they would imitate a diſtant echo, generally take the ſounds an octave higher. A few years ago, a fellow exhibited in Weſtminſter the art of imitating ſounds at any diſtance whatever. I remarked, that whenever he deſigned to imitate a voice coming from a great diſtance, he not only made the ſound more low and indiſtinct, but raiſed the tone ſeveral

Some curious experiments were made, relative to the propagation of ſound, by Meſſieurs de Thury, Maraldi, and de la Caille, upon a line fourteen thouſand ſix hundred and thirty-ſix fathoms in length, having the tower of Mount Lhéri at one end, and the pyramid of Montmartre at the other extremity of that diſtance: their obſervatory was placed between thoſe two objects. The reſult of their obſervations were theſe, 1ſt. That ſound moves one hundred and ſeventy-three fathoms French in a ſecond, when the air is calm. 2d. That ſound

veral pitches higher than that uſed in his nearer imitations. A few obſervations ſince made upon ſounds, induce me to believe, that they become higher as they come from a diſtance more remote; while, on the contrary, that they deepen the more the vibrations approach the labyrinth of the ear. The following eaſy and common experiment, I think, will prove it. Take any thing whatever, capable of giving a ſound; let it be a common poker for inſtance, and tying on a garter at top, ſo as that both ends of the garter are left at liberty; theſe ends muſt be rolled round the firſt finger of each hand, and then with theſe fingers ſtopping the ears cloſe, ſtrike the poker thus ſuſpended againſt any body whatſoever. The depth of the tone which this new muſical inſtrument returns will be amazing. The deepeſt and largeſt bell will not equal it. Whence is this, unleſs from the cloſe approach of the ſounding body, whoſe vibrations are immediately communicated to the internal parts of the ear. I am ſenſible that many objections may be made to this laſt opinion; ſucceeding experience muſt, however, determine whether it be juſt or not: but ſuch as make them muſt be particularly careful not to let their former experience correct their immediate ſenſations. This alteration of tone, with diſtance, however, muſt diminiſh but by great intervals. *Goldſmith's Philoſophy*, vol. ii. p. 195, 196.

moves

moves with the ſame degree of ſwiftneſs whether it is ſtrong or weak; for theſe gentlemen obſerved, that the diſcharge of a box of half a pound of gun-powder exploded at Mountmartre was heard at Mount Lhéri in the ſame ſpace of time as the report of a great gun charged with nearly ſix pounds of powder. 3d. That the motion of ſound is uniform; that its velocity neither accelerates nor diminiſhes through all the intervals of its progreſs, as is the caſe with almoſt every other ſpecies of motion. 4th. That the velocity of ſound is the ſame, whether a cannon is placed towards the perſon who hears its report, or turned a contrary way; in other words, a great gun fired from the Tower of London eaſtward, would be heard at Weſtminſter in the ſame interval of time as if it was diſcharged towards the latter place. And if the gun was diſcharged in a direction perpendicular to the horizon, it would be heard as ſoon as if diſcharged in a right line towards the hearer. By other experiments, however, the progreſs of ſound appears to be impeded by a ſtrong wind, ſo that it travels at the rate of about one mile ſlower in a minute againſt a ſtrong wind than with it.

A knowledge of the progreſſion of ſound is not an article of mere ſterile curioſity, but in ſeveral inſtances uſeful; for by this we are enabled to determine the diſtance of ſhips or other moving bodies. Suppoſe, for example, a veſſel fires a gun, the ſound of which is heard five ſeconds after the flaſh is ſeen; as ſound moves 1142 Engliſh

liſh feet in one ſecond, this number multiplied by 5 gives the diſtance of 5710 feet. The ſame principle has been already noticed as applied to ſtorms of lightning and thunder.

The waves or pulſes of ſound being reflexible in their courſe when they meet with an extended ſolid body of a regular ſurface, an ear placed in the paſſage of theſe reflected waves will perceive a ſound ſimilar to the original ſound, but which will ſeem to proceed from a body ſituated in a ſimilar poſition and diſtance behind the plane of reflection, as the real ſounding body is before it. This reflected ſound is commonly called an ECHO, which, however, cannot take place at leſs than fifty-five feet; becauſe it is neceſſary that the diſtance ſhould be ſuch, and the reverberated or reflected ſound ſo long in arriving, that the ear may diſtinguiſh clearly between that and the original ſound *.

Reflected

* " It is in general known, that caverns, grottoes, mountains, and ruined buildings return this image of ſound. Image we may call it, for in every reſpect it reſembles the image of a viſible object reflected from a poliſhed ſurface. Our figures are often repreſented in a mirror without ſeeing them ourſelves, while thoſe ſtanding on one ſide are alone ſenſible of the reflection. To be capable of ſeeing the reflected image of ourſelves, we muſt be directly in a line with the image. Juſt ſo is it in an echo; we muſt ſtand in the line in which the ſound is reflected, or the repetition will be loſt to us, while it may, at the ſame time, be diſtinctly heard by others who ſtand at a ſmall diſtance to one ſide of us. I remember a very extraordinary echo, at a ruined fortreſs near Louvain, in Flanders. If a perſon ſung, he only heard his own voice, without any repetition; on

Reflected found may be magnified by much the fame contrivances as are ufed in optics refpecting

on the contrary, thofe who ftood at fome diftance, heard the echo but not the voice; but then they heard it with furprifing variations, fometimes louder, fometimes fofter, now more near, then more diftant. There is an account, in the memoirs of the French academy, of a fimilar echo near Rouen. The building which returns it is a femicircular court-yard; yet all buildings of the fame form do not produce the fame effects. We find fome mufic halls excellently adapted for founds, while others, built upon the fame plan, in a different place, are found to mix the tones, inftead of enlarging them, in a very difagreeable manner.

" As we know the diftance of places by the length of time a found takes to travel from them, fo we may judge of the diftance of an echo, by the length of the interval between our voice and its repetition. The moft deliberate echoes, as they are called, are ever the moft diftant; while, on the contrary, thofe that are very near, return their founds fo very quick as to have the interval almoft imperceptible; when this is the cafe, and the echo is fo very near, the voice is faid to be increafed and not echoed; however, in fact, the increafe is only made by the fwiftly purfuing repetition. Our theatres and concert rooms are beft fitted for mufic or fpeaking, when they enlarge the found to the greateft pitch at the fmalleft interval: for a repetition which does not begin the word till the fpeaker has finifhed it, throws all the founds into confufion. Thus the theatre at the Hay-market enlarges the found very much; but then at a long interval after the finger or fpeaker. The theatre at Drury-lane, before it was altered, enlarged the found but in a fmall degree; but then the repetition was extremely quick in its purfuit, and the founds, when heard, were therefore heard diftinctly. Dergolife, the great mufical compofer, ufed to fay, that an echo was the beft fchool-miftrefs; for let a man's own mufic be ever fo good, by playing to an echo fhe would teach him to improve it." *Goldfmith's Philofophy*, vol. ii. p. 201—204.

light:

light: hence it follows, that ſounds uttered in one focus of an elliptical cavity are heard much magnified in the other focus. The whiſpering gallery at St. Paul's cathedral in London is of this deſcription; a whiſper uttered at one ſide of the dome is reflected to the other, and may be very diſtinctly heard. The ſpeaking and ear trumpets are conſtructed on this principle. The beſt form for theſe inſtruments is a hollow parabolic conoid, with a ſmall orifice at the top or apex, to which the mouth is applied when the ſound is to be magnified, or the ear when the hearing is to be facilitated.

The ſtructure of the ear is one of the moſt complicated and difficult ſubjects of phyſiology, and it could ſcarcely be comprehended without ſome previous knowledge of the conſtituent parts of the animal frame; for this reaſon it will be neceſſary to defer the conſideration of the manner in which we receive ideas of ſound, till I come to treat of that part of the animal œconomy which reſpects the ſenſe of hearing.

Chap. XI.

WINDS.

Different Opinions concerning the general Cause of Winds.—Of General or Trade Winds.—Of Monsoons.—Of Sea and Land Breezes.—Causes of these.—Variable Winds.—Storms.—Hurricanes.—The Harmattan.—The Sirocco Wind.—The Samiel.—Moving Pillars of Sand.—The Simoom.—Whirlwinds.—Water-spouts.—Tornadoes.

THE opinions of philosophers have varied much respecting the cause of winds, and many of their theories are little more than mere conjectures; but it must be confessed, that electricity and a chemical knowledge of air have latterly in some degree improved our imperfect acquaintance with these aerial currents.

It has been already observed, that air is expanded by heat, and its spring consequently increased; and it is well known also that its elasticity is weakened by cold or freezing mixtures. From experiments which have been made for the illustration of these properties of air, we are enabled to point out the causes of many phenomena that occur in the atmosphere.

When a fire is made in the open air, the rarefied part of that fluid will ascend in a current, and the cooler and denser air will rush in on all sides, in consequence of which a wind is generated, which

which blows conſtantly towards the fire. The wind produced in this manner will be too inconſiderable to be perceived at any great diſtance; but the rarefactions which ariſe from natural cauſes may be ſuch as to agitate our atmoſphere ſufficiently to produce thoſe torrents of air which have always a powerful effect in nature, and which ſometimes overwhelm and deſtroy the faireſt productions of human art.

M. Briſſon is inclined to believe, that electricity is the firſt and general cauſe of all variable winds: 'Thunder and water-ſpouts *,' ſays he, 'are now acknowledged to be electrical phenomena, and theſe are frequently accompanied with formidable winds. Why may not the cauſe which produces theſe phenomena be alſo that of the winds which accompany them? If electricity is the cauſe of theſe winds, why may it not be the cauſe of the others †?'

Winds are commonly divided into three claſſes, viz. general, periodical, and variable winds.

General or permanent winds blow always nearly in the ſame direction. In the Atlantic and Pacific Oceans, under the equator, the wind is almoſt always eaſterly; it blows, indeed, in this direction, on both ſides of the equator to the latitude of 28°. More to the northward of the equator, the wind generally blows between the north and eaſt, and the far-

* Of the latter I entertain many doubts, at leaſt as to electricity being the proximate or efficient cauſe. See the latter part of this chapter.

† Briſſon, Traité Elem. de Phyſique, tom. ii. p. 180.

ther north we proceed, we find the wind to blow in a more northern direction; more to the southward of the equator it blows between the south and east, and the farther to the south, the more it comes in that direction.

Between the parallels of 28° and 40° south lat. in that tract which extends from 30° west to 100° east longitude from London, the wind is variable, but it most frequently blows from between the N. W. and S. W. so that the outward bound East India ships generally run down their easting on the parallel of 36° south *.

Navigators have given the appellation of *trade-winds* to these general winds.

Those winds, which blow in a certain direction for a time, and at certain stated seasons change and blow for an equal space of time from the opposite point of the compass, are called *monsoons*. During the months of April, May, June, July, August, and September, the wind blows from the southward over the whole length of the Indian Ocean; *viz.* between the parallels of 28° N. and 28° S. lat. and between the eastern coast of Africa and the meridian which passes through the western part of Japan; but in the other months, October, November, December, January, February, and March, the winds in all the northern parts of the Indian Ocean shift round, and blow directly contrary to the course they held in the former six months. For some days before and after the change,

* See Nicholson's Phil. vol. ii. p. 56.

there are calms, variable winds, and tremendous ftorms, with thunder, &c.

Philofophers differ in their opinions refpecting the caufe of thefe periodical winds; but a moft probable theory of the general trade-winds is, that they are occafioned by the heat of the fun in the regions about the equator, where the air is heated to a greater degree, and confequently rarefied more than in the more northern parts of the globe. From this expanfion of the air in thefe tropical regions, the denfer air, in higher latitudes, rufhes violently towards the equator from both fides of the globe. By this conflux of the denfer air, without any other circumftances intervening, a direct northerly wind would be produced in the northern tropic, and a fouthern one in the other tropic; but as the earth's diurnal motion varies the direct influence of the fun over the furface of the earth, and as by that motion this influence is communicated from eaft to weft, an eafterly wind would be produced, if this influence alone prevailed. On account of the co-operation of thefe two caufes at the fame time, the trade-winds blow naturally from the N. E. on the north, and from the S. E. on the fouth of the line, throughout the whole year; but as the fun approaches nearer the tropic of *Cancer* in our fummer feafon, the point towards which thefe winds are directed will not be invariably the fame, but they will incline more towards the north in that feafon, and more towards the fouth in our winter.

The *land* and *fea breezes* in the tropical climates may be confidered as partial interruptions of the ge-

 neral

neral trade winds, and the cauſe of theſe it is not very difficult to explain. From water being a better conductor of heat than earth, the water is always of a more even temperature. During the day, therefore, the land becomes conſiderably heated, the air rarefied, and conſequently in the afternoon a breeze ſets in from the ſea, which is leſs heated at that time than the land. On the other hand, during the night the earth loſes its ſurplus heat, while the ſea continues more even in its temperature. Towards morning, therefore, a breeze regularly proceeds from the land towards the ocean, where the air is warmer, and conſequently more rarefied than on ſhore.

The cauſe of the monſoons is not ſo well underſtood as that of the general trade winds; but what has been juſt remarked, ſuggeſts, at leaſt, a probable theory on the ſubject. It is well known, that at the equator the changes of heat and cold are occaſioned by the *diurnal* motion of the earth, and that the difference between the heat of the day and the night is almoſt all that is perceived in thoſe tropical regions; whereas in the polar regions the great viciſſitudes of heat and cold are occaſioned by the *annual* motion of the globe, which produces the ſenſible changes of *winter* and *ſummer*; conſequently, if the heat of the ſun was the only cauſe of the variation of the winds, the changes, if any, that would be produced by thoſe means in equatorial regions, ought to be *diurnal* only, but the changes about the *pole* ſhould be experienced only once in ſix months. As the effects ariſing from the heat of the ſun upon the air muſt be greater at the equator than at the poles, the changes of the wind

wind ariſing from the expanſion of the air by the ſun's rays muſt be more ſteady in equatorial than in polar regions. The incontrovertible evidence of navigators proves this truth, that winds are more variable towards the poles, and more conſtant towards the equator. But in ſummer, the continual heat, even in high latitudes, comes to be ſenſibly felt, and produces changes on the wind, which are diſtinctly perceptible. In our own cold region, the effects of the ſun on the wind are felt during the ſummer months; for while the weather in that ſeaſon of the year is fine, the wind generally becomes ſtronger as the time of the day advances, and dies away towards the evening, and aſſumes that pleaſing ſerenity ſo delightful to our feelings. Such are the diurnal changes of the wind in northern climates. The *annual* revolution of the ſun produces ſtill more ſenſible effects. The prevalence of the weſtern winds during ſummer, we may attribute to this cauſe, which is ſtill more perceptible in France and Spain; becauſe the continent of land to the eaſtward, being heated more than the waters of the Atlantic Ocean, the air is drawn, during that ſeaſon, towards the eaſt, and conſequently produces a weſtern wind.

But theſe effects are much more perceptible in countries near the tropics than with us. For when the ſun approaches the tropic of Cancer, the ſoil of Perſia, Bengal, China, and the adjoining countries, becomes ſo much more heated than the ſea to the ſouthward of thoſe countries, that the current of the general trade wind is

 interrupted,

interrupted, ſo as to blow, at that ſeaſon, from the ſouth to the north, contrary to what it would do if no land was there. But as the high mountains of Africa, during all the year, are extremely cold, the low countries of India, to the eaſtward of it, become hotter than Africa in ſummer, and the air is naturally drawn thence to the eaſtward. From the ſame cauſe it follows, that the trade wind, in the Indian Ocean, from April till October, blows in a north-eaſt direction, contrary to that of the general trade wind, in open ſeas, in the ſame latitude; but when the ſun retires towards the tropic of Capricorn, theſe northern parts become cooler, and the general trade wind aſſumes its natural direction.

Having given the moſt obvious cauſes of the periodical monſoons in the Indian ſeas, it is neceſſary to obſerve, that no monſoon takes place to the ſouthward of the equator, except in that part of the ocean adjoining to New Holland. There the ſame cauſes concur to produce a monſoon as in the northern tropic, and ſimilar appearances take place. From October till April the monſoon ſets in from the N. W. to S. E. oppoſite to the general courſe of the trade wind on the other ſide of the line; and here alſo the general trade wind reſumes its uſual courſe during the other months, which conſtitute the winter ſeaſon in theſe regions. It may not be improper to conclude this account of the tropical winds, by enumerating ſome of the principal inflections of the monſoons.

Between

Between the months of April and October the wind blows constantly from W. S. W. in all that part of the Indian ocean which lies between Madagascar and Cape Commorin, and in the contrary direction from October till April, with some small variation in different places; but in the bay of Bengal these winds are neither so strong nor so constant as in the Indian ocean. It must also be remarked, that the S. W. winds in those seas are more southerly on the African side, and more westerly on the side of India; but these variations are not so great as to be repugnant to the general theory. The cause of this variation is, as was before intimated, that the mountainous lands of Africa are colder than the flatter regions of Arabia and India, consequently the wind naturally blows from these cold mountains, in the summer season, towards the warmer lands of Asia, which occasions those inflections of the wind to the eastward during the summer months. The peninsula of India, lying so much farther to the south than the kingdoms of Arabia and Persia, adds greatly to this effect, because the wind naturally draws towards them, and produces that easterly variation of the monsoon which takes place in this part of the ocean, while the sandy deserts of Arabia draw the winds more directly northward, near the African coast. A similar chain of reasoning will serve to explain any other inflexions or variations that may occur in the perusal of books of travels, &c.

The variable winds, which take place in these climates, depend upon different causes; but I am inclined to agree with M. Brisson in attributing them chiefly to electricity. It is to be remembered, that whatever destroys the equilibrium of the air, in other words, any cause which produces a sudden rarefaction in any part of the atmosphere, produces a current of wind towards the part where the rarefaction takes place; winds are, therefore, not only produced by the earth being heated in a particular part, but by thunder storms or other electrical phenomena. The rays of the sun are also sometimes obstructed by clouds or mists in particular places, and one part of the world, or even of a particular country, will consequently be less heated than another; in that case there will always be a current of air from the cold to the warm region. Besides this, the falling of rain, or other circumstances, produce occasional alterations in the temperature; and whenever these take place in any country, they must be attended with wind. The great Bacon was the first who attempted a theory of the wind; and it is to be lamented that his plan has not been pursued by succeeding philosophers. The following is a sketch of his general principles, with a few additions by modern observers.

'At sea the winds are more regular than at land; for there nothing opposes their progress, or alters the sun's influence.

'The air at sea is more equable, as well as more constant: at land it blows in fits of force and intermission; but at sea the current is strong, steady, and even.

'In general, at sea, on this side the equator, the east and north winds are most violent and boisterous:

ous: on the contrary, at land, the weſt and ſouth winds are moſt ſubject to produce hurricanes and tempeſts.

'The air is often ſeen to move in two contrary currents, and this almoſt ever previous to thunder. The clouds, in ſuch a caſe, are ſeen to move one way, while the weathercock points another.

'The winds are more violent at certain heights than upon the plain, and the higher we aſcend lofty mountains, the greater is the force of the wind, till we get above the ordinary height of the clouds. Above this the ſky is uſually ſerene and clear. The reaſon is, that the wind, at the ſurface of the earth, is continually interrupted by hills and riſings: ſo that, on the plain, between any two of theſe, the inhabitants are in a kind of ſhelter; but when once the interpoſition of ſmall hills no longer ſtops the wind's courſe, it then becomes ſtronger, as the interruptions it meets with are fewer. At the tops of the higher mountains its interruptions are leaſt of all; but it does not blow with violence there; for its denſity is ſo much diminiſhed by the height, that its force is ſcarcely perceptible, and the ſtorm falls midway below. What is commonly called a high wind moves at the rate of about thirty-five miles an hour.

'A current of air always augments in force in proportion as the paſſage through which it runs is diminiſhed. The law of this augmentation is, that the air's force is compounded of its ſwiftneſs and denſity, and as theſe are increaſed, ſo will the force of the wind. If any quantity of wind moves with twice

twice the ſwiftneſs of a ſimilar quantity, it will have twice its force; but if, at the ſame time that it is twice as ſwift, it moves through twice a ſmaller tube, and the ſides of the canal give no reſiſtance to its motion, it will have four times the force. This, however, is not entirely the caſe; for the ſides of the tube give a reſiſtance, and retard its motion, in a proportion that is not eaſily calculated. From this increaſe of the wind's denſity in blowing through narrow paſſages, it is that we ſee the ſtorms ſo very violent that ſometime blow between two neighbouring hills. It is from this, that when caught in long arcades opening at one end, the wind blows with great force along them. From this increaſed denſity it is, that we meet with ſuch cold blaſts at the corners of ſtreets. In ſhort, whatever diminiſhes its bulk, without taking entirely away from its motion, increaſes the vehemence of the wind. This alſo is the reaſon why the air reflected back from the ſide of a mountain is often more violent than the air which firſt ſtruck its ſide; for it is by this means condenſed, and its force augmented. The countrymen and farmers have a diſtinction which is not without its foundation; for they make a difference between a ſwift and an heavy ſtorm: the ſwift ſtorm is loud, boiſterous, and inoffenſive; the heavy ſtorm more boiſterous and alſo more dangerous. This ſhews the inſufficiency of thoſe inſtruments made for meaſuring winds, by meaſuring the rapidity only with which they move *.'

* Goldſmith's Philoſophy, vol. ii. p. 143.

It

It would be happy indeed for ſcience and for mankind if theſe reſearches could have been carried further. To predict an eclipſe, ſays a late writer, is an object merely of curioſity; to predict an approaching ſtorm would be of inconceivable benefit. What is ſtill unaccompliſhed with reſpect to our own climate, has however been attempted with reſpect to thoſe alarming ſtorms which happen in the Weſt Indies, which are commonly denominated hurricanes.

Theſe dreadful convulſions of nature, Dr. Perkins ſuppoſes to be cauſed by ſome occaſional obſtruction in the uſual and natural progreſs of the equatorial trade winds. The reaſon he aſſigns for this conjecture is, the more than uſual calm which commonly precedes them. In the natural courſe of the trade winds, the air riſes up in the line, and paſſes off towards the poles, and, in the more contracted degrees of the higher latitudes, takes the courſe of the weſt trade winds, ſo that could their aſcent be prevented through the whole circle of the zone, there would be no more weſt winds in thoſe latitudes than in any other. Very violent rains and cold, however, tend to check the aſcent of air out of this circle, rather cauſing it to deſcend. Great clouds and vapour generate cold and wet, while rain beats down the air; and as theſe prevent the riſing of the air out of the line, ſo they hinder its uſual progreſs from the tropics on both ſides; hence the calms which uſually precede hurricanes. Calms, in theſe tropical regions, are cauſed by the aſcent of the air into the higher part of the atmoſphere, inſtead of its remaining near the line: the accumulation of air above then becomes heavier by the cold which it meets in thoſe regions, and deſcends into the more rarefied region below. Theſe heavy gales, therefore, will continue to deſcend till the upper regions are entirely exonerated.

In Mr. Beckford's hiſtory of Jamaica there is a very detailed and ſtriking account of the dreadful hurricane which deſolated the iſlands in the year 1780, but it is too long for inſertion as an extract, and in an abridged ſtate the deſcription would loſe its force. ' It is in the rainy ſeaſon (ſays Mr. Adams) principally in the month of Auguſt, that they are aſſaulted by hurricanes, which deſtroy at a ſtroke the labours of many years, and proſtrate the moſt exalted hopes of the planter, and that, often when he thinks himſelf out of the reach of fortune. It is a ſudden and violent ſtorm of wind, rain, thunder, and lightning, attended with a furious ſwelling of the ſeas, and ſometimes with an earthquake; in ſhort, with every circumſtance which the elements can aſſemble, that is terrible and deſtructive. Firſt, they ſee, as a prelude to the enſuing havock, whole fields of ſugar canes whirled into the air, and ſcattered over the face of the country. The ſtrongeſt trees of the foreſt are torn up by the roots, and driven about like ſtubble; their wind-mills are ſwept away in a moment; their works, the fixtures, the ponderous copper-boilers, and ſtills of ſeveral hundred weight, are wrenched from the ground and battered

battered to pieces; their houſes are no protection; their roofs are torn off at one blaſt, whilſt the rain, which in an hour riſes five feet, ruſhes in upon them with irreſiſtible violence.

There are ſigns by which the Indians of theſe iſlands taught our planters to prognoſticate the approach of an hurricane. The hurricane comes on either in the quarter or at the full change of the moon. If it comes on at the full, then, at the preceding change, the ſky is troubled, the ſun more red than uſual; there is a dead calm below, and the mountain tops are free from thoſe miſts which uſually hover about them. In the caverns of the earth, and in wells, you hear a hollow rumbling ſound, like the ruſhing of a great wind. At night the ſtars ſeem much larger than uſual, and ſurrounded with a ſort of burs; the north-weſt ſky has a black and menacing appearance; the ſea emits a ſtrong ſmell, and riſes into vaſt waves often without any wind. The wind itſelf now forſakes its uſual ſteady eaſterly ſtream, and ſhifts about to the weſt; whence it ſometimes, with intermiſſions, blows violently and irregularly about two hours at a time. You have the ſame ſigns at the full moon: the moon herſelf is ſurrounded with a great bur, and ſometimes the ſun has the ſame appearance *.'

The harmattan is a very ſingular wind, which blows periodically from the interior parts of Africa towards the Atlantic Ocean. The ſeaſon in which it prevails is during the months of December, Ja-

* Adams's Lectures, vol. iv. p. 540.

nuary,

nuary, and February; it comes on indifcriminately at any hour of the day, at any time of the tide, or at any period of the moon, and continues fometimes only a day or two, fometimes five or fix days, and it has been known to laft fifteen and fixteen days. There are generally three or four returns of it every feafon. It blows with a moderate force, but not quite fo ftrong as the fea breeze.

A fog or haze is one of the peculiarities which always accompany the harmattan. The Englifh, French, and Portuguefe forts at Whydah, are not quite a quarter of a mile afunder, yet are frequently quite invifible to each other; the fun, concealed the greateft part of the day, appears only about a few hours at noon, and then of a mild red, exciting no painful fenfation on the eye. The particles which conftitute this fog are depofited on the leaves of trees, on the fkins of the negroes, &c. and make them appear whitifh.

Extreme drynefs makes another extraordinary property of this wind; no dew falls during its continuance; vegetables are withered, and the grafs becomes dry like hay. The natives take this opportunity to clear the land, by fetting fire to the trees and plants while in that dry and exhaufted ftate. The drynefs is fo extreme, that the covers of books, even clofely fhut up in a trunk, are bent as if expofed to the fire. Houfhold furniture is much damaged; the pannels of wainfcots fplit, and fineered work flies to pieces. The joints of a well-laid floor of feafoned wood open fufficiently to ad-

mit

mit the breadth of a finger between them; but become as close as before on the ceasing of the harmattan. The human body does not escape the parching effects of this wind; the eyes, nostrils, lips, and palate, are rendered dry and uneasy; the lips and nose become sore, and though the air is cool, there is a troublesome sensation of pricking heat on the skin. If the harmattan continues four or five days, the scarf-skin peels off, first from the hands and face, and afterwards from the rest of the body.

Though this wind is so fatal to vegetable life, and occasions these troublesome effects to the human species, it is nevertheless highly conducive to health; it stops the progress of epidemics, and relieves the patients labouring under fluxes and intermittent fevers. Infection is not easy at that time to be communicated, even by inoculation. It is also remarkable for the cure of ulcers and cutaneous diseases *.

The sirocco (so called by the Italians because it is supposed to blow from Syria, and in the South of France, the Levant wind) resembles in some of its effects the harmattan, but it differs from it in being extremely insalubrious. It sometimes blows for several days together, to the great annoyance of the whole vegetable and animal creation; its medium heat is calculated at 112 degrees; it is fatal to vegetation and destructive to mankind, and especially to

* Dobs. Account, Phil. Transf. vol. lxxi. part 1.

strangers;

ſtrangers; it depreſſes the ſpirits in an unuſual degree; it ſuſpends the powers of digeſtion, ſo that thoſe who venture to eat a heavy ſupper while this wind prevails are commonly found dead in their beds the next morning, of what is called an indigeſtion. The ſick, at that afflicting period, commonly ſink under the preſſure of their diſeaſes; and it is cuſtomary in the morning, after this wind has continued a whole night, to inquire who is dead *.

'An

* 'The evil moſt to be dreaded in traverſing theſe regions is, perhaps, the ſirocc, or ſouth wind, which it is imagined blows from the burning deſerts of Africa, and is ſometimes productive of dangerous conſequences to thoſe who are expoſed to its fury. During the continuance of this wind all nature appears to languiſh, vegetation withers and dies, the beaſts of the field droop, the animal ſpirits ſeem too much exhauſted to admit of the leaſt bodily exertion, and the ſpring and elaſticity of the air appear to be loſt. The heat exceeds that of the moſt fervid weather in Spain or Malta, and is felt with peculiar violence in the city and neighbourhood of Palermo.

'The ſenſation occaſioned by the ſirocc wind is very ſtriking and wonderful. In a moment the air becomes heated to an exceſſive degree, and the whole atmoſphere feels as if it were inflamed, the pores of the body ſeem at once opened, and all the fibres relaxed. During its continuance the inhabitants of Palermo ſhut their doors and windows to exclude the air, and where there are no window ſhutters, wet blankets are hung on the inſide of the window, and the ſervants are kept continually employed in ſprinkling the apartments with water. No creature, whoſe neceſſities do not compel him to the exertion, is to be ſeen while this tremendous wind continues to blow, and the ſtreets and avenues of the city appear to be nearly deſerted.

'The ſirocc generally continues ſo ſhort a time in Sicily, that it ſeldom produces thoſe complaints which are the conſe-

quence

'An extraordinary blafting wind is felt occafionally at Falklands Iflands. Happily its duration is fhort: it feldom continues above twenty-four hours. It cuts the herbage down as if fires had been made under them; the leaves are parched up, and crumble into duft. Fowls are feized with cramps fo as never to recover. Men are oppreffed with a ftopped perfpiration, heavinefs at the breaft, and fore throat; but recover with care.

'But beyond all others in its dreadful effects, is the famiel, or mortifying wind, of the defarts near

quence of the duration of its fcorching heats in feveral parts of Italy, though its violence in thofe countries is much inferior to what is felt in this ifland. Here it feldom endures longer than thirty-fix or forty hours, a time not fufficient to heat the ground, or the walls of the houfes, in a very intenfe continued degree. It is commonly fucceeded by the tramontane, or north wind, which in a fhort time reftores the exhaufted powers of animal and vegetable life, and nature foon affumes her former appearance. The caufe of the firocc wind has been frequently attempted to be explained, but the different hypothefes are perhaps more to be admired for their ingenuity and fancy than for being very fatisfactorily explained. The fuperior intenfenefs of this fcorching wind at Palermo, may probably be accounted for from the fituation of that city, which is almoft furrounded by lofty mountains, the ravines and valleys of which are parched and almoft burnt up in fummer. The numberlefs fprings of warm water muft alfo greatly increafe the heat of the air, and the practice of burning brufh wood and heath on the neighbouring mountains, during the warm feafon, muft undoubtedly tend to increafe the heat of the wind in paffing over the country of Sicily, though it had previoufly been difarmed of part of its violence by travelling over the fea which divides Sicily from Africa." *Prefent State of Sicily and Malta,* p. 189.

 Bagdad,

Bagdad. The camels, either by inſtinct or experience, have notice of its approach, and are ſo well aware of it, that they are ſaid to make an unuſual noiſe, and cover up their noſes in the ſand. To eſcape its effects, travellers throw themſelves as cloſe as poſſible to the ground, and wait till it has paſſed by, which is commonly in a few minutes. As ſoon as they who have life dare to riſe again, they examine how it fares with their companions, by plucking at their arms or legs; for if they are deſtroyed by the wind, their limbs are abſolutely mortified, and will come aſunder. It is ſaid of this wind, that if it happens to meet with a ſhower of rain in its courſe, and blows acroſs it, it is at once deprived of its noxious quality, and becomes mild and innocent. It is alſo ſaid, that it was never known to paſs the walls of a city *.'

This account of the ſamiel is extracted from the travels of Mr. Ives over land to the Eaſt Indies. Whether this wind is identically the ſame with that which is deſcribed by Mr. Bruce under the name of the ſimoom, I cannot determine. The facts in both accounts have a very cloſe agreement, and the climate and ſituation where they occur are not materially different. In the ſame deſert Mr. Bruce obſerved the aſtoniſhing phenomenon of moving pillars of ſand †, which are probably the effects of a number

* See Adams's Lectures. vol. iv. p. 541.

† " So where our wide Numidian waſtes extend,
Sudden th' impetuous hurricanes deſcend,

'Wheel

number of whirlwinds in thofe torrid regions. As the defcription of thefe pillars is in fome degree blended with that of the fimoom, I fhall extract the whole paffage. In relating the particulars of his journey acrofs a certain part of the deferts of Africa, Mr. Bruce obferves 'We were here at once furprifed and terrified by a fight furely one of the moft magnificent in the world. In that vaft expanfe of defert, from weft and to north weft of us, we faw a number of prodigious pillars of fand at different diftances, at times moving with great celerity, at others ftalking on with a majeftic flownefs; at intervals we thought they were coming in a very few minutes to overwhelm us; and fmall quantities of fand did actually more than once reach us. Again they would retreat fo as to be almoft out of fight, their tops reaching to the very clouds. There the tops often feparated from the bodies; and thefe, once disjoined, difperfed in the air, and did not appear more. Sometimes they were broken near the middle, as if ftruck with a large cannon fhot. About noon they began to advance with confiderable fwiftnefs upon us, the wind being very ftrong at north. Eleven of them ranged alongfide of us about the diftance of three miles. The greateft diameter of the largeft ap-

Wheel through the air, in circling eddies play,
Tear up the fands, and fweep whole plains away;
Th' affrighted traveller, with wild furprife,
Sees the dry defert all around him rife,
And, fmother'd in the dufty whirlwind, dies."

Addifon's Cato.

peared to me at that diftance, as if it would meafure ten feet. They retired from us with a wind at fouth eaft; leaving an impreffion upon my mind to which I can give no name, though furely one ingredient in it was fear, with a confiderable deal of wonder and aftonifhment. It was in vain to think of flying; the fwifteft horfe, or fafteft failing fhip, could be of no ufe to carry us out of this danger; and the full perfuafion of this rivetted me as if to the fpot where I ftood, and let the camels gain on me fo much in my ftate of lamenefs, that it was with fome difficulty I could overtake them.'

The fame phenomena again occurred in the courfe of a few days. ' The fame appearance of moving pillars of fand prefented themfelves to us this day, in form and difpofition like thofe we had feen at Waadi Halboub, only they feemed to be more in number, and lefs in fize. They came feveral times in a direction clofe upon us; that is, I believe, within lefs than two miles. They began immediately after fun-rife, like a thick wood, and almoft darkened the fun: his rays fhining through them for near an hour, gave them an appearance of pillars of fire. Our people now became defperate: the Greeks fhrieked out, and faid it was the day of judgment. Ifmael pronounced it to be hell, and the Tucorories, that the world was on fire. I afked Idris if ever he had before feen fuch a fight? he faid he had often feen them as terrible, though never worfe; but what he feared moft was that extreme rednefs in the air, which was a fure prefage of the

coming

coming of the ſimoom. I begged and intreated Idris that he would not ſay one word of that in the hearing of the people, for they had already felt it at Imhanſara, in their way from Ras el Feel to Teawa, and again at the Acaba of Gerri, before we came to Chendi, and they were already nearly diſtracted at the apprehenſion of finding it here.

‘ At half paſt four o'clock in the afternoon, we left Waadi Del Aned, our courſe a little more to the weſtward than the direction of Syene. The ſands which had diſappeared yeſterday ſcarcely ſhewed themſelves at all this day, and at a great diſtance from the horizon. This was, however, a comfort but of ſhort duration. I obſerved Idris took no part in it, but only warned me and the ſervants, that, upon the coming of the ſimoom, we ſhould fall upon our faces, with our mouths upon the earth, ſo as not to partake of the outward air as long as we could hold our breath. We alighted at ſix o'clock at a ſmall rock in the ſandy ground, without trees or herbage, ſo that our camels faſted all that night. This place is called Ras el Sheah, or, by the Biſhareen, El Mout, which ſignifies death, a name of bad omen.

‘ On the 16th, at half paſt ten in the forenoon, we left El Maut, ſtanding in the direction cloſe upon Syene. Our men, if not gay, were, however, in better ſpirits than I had ſeen them ſince we left Gooz. One of our Barbarins had even attempted a ſong; but Hagi Iſmael very gravely reproved him, by telling him, that ſinging in ſuch a ſituation was a tempting of Providence. There is, indeed, nothing more different than active and paſſive courage. Hagi Iſmael would fight, but he had not ſtrength of mind to ſuffer. At eleven o'clock, while we contemplated with great pleaſure the rugged top of Chiggre, to which we were faſt approaching, and where we were to ſolace ourſelves with plenty of good water, Idris cried out, with a loud voice, Fall upon your faces, for here is the ſimoom. I ſaw from the ſouth eaſt a haze come, in colour like the purple part of the rainbow, but not ſo compreſſed or thick. It did not occupy twenty yards in breadth, and was about twelve feet high from the ground. It was a kind of bluſh upon the air, and it moved very rapidly, for I ſcarce could turn to fall upon the ground with my head to the northward, when I felt the heat of its current plainly upon my face. We all lay flat on the ground, as if dead, till Idris told us it was blown over. The meteor, or purple haze, which I ſaw, was indeed paſſed, but the light air that ſtill blew was of heat to threaten ſuffocation. For my part, I found diſtinctly in my breaſt, that I had imbibed a part of it; nor was I free of an aſthmatic ſenſation till I had been ſome months in Italy, at the baths of Poretta, near two years afterwards *.'

Whirlwinds and water-ſpouts have by many philoſophers been conſidered as entirely electrical phenomena, while others have attributed them to a

* Bruce's Travels. Vol. iv. p. 553, 555.

different

different cauſe, and accounted for them upon the principles of hydroſtatics. It is poſſible, however, that there may really be two kinds of water-ſpouts, the one the effect of the electrical attraction, as deſcribed in Book iv. c. 6. and the other cauſed by a vacuum, or extreme and ſudden rarefaction of the air. The whirlwinds at leaſt, which I have obſerved in this country, were, I am perſuaded, of the latter kind; at leaſt whatever was the original cauſe, the circumagitation or ſpiral motion of the air muſt have continued long after every electrical power had ceaſed to act.

It is well known that even a common fire produces a kind of circulation of the air in a room, but in a different form. It is therefore not difficult to conceive, that when any part of the column of air upon the ſurface of the earth or water is ſuddenly rarified, either by electricity or any other cauſe, a vacuum, at leaſt comparatively to the reſt of the air, will immediately take place, and, the circumambient air ruſhing in at once from every quarter to fill the void, a conflict of winds enſues; and conſequently a circular motion, by which light bodies will be taken up and turned round with conſiderable velocity; this violent ruſhing of the air on all ſides into the vacuum then forms what is commonly called at land a whirlwind.

When this vacuum takes place at ſea, from the nature of fluids, the water will riſe to a certain height by the preſſure of the atmoſphere, as in a common pump; but as the vacuum is not quite perfect, the water will be divided into drops, and as these vacuums are generally caused by heat, it will be rarefied when it reaches the upper regions of the atmosphere, and assume the appearance of a cloud.

Mr. Oliver *, whose theory I have adopted with little variation, illustrates the phenomenon by a very easy experiment. In a stiff paper card he made a hole just large enough to insert a goose quill; after cutting the quill off square at both ends, he laid the card upon the mouth of a wine glass, filled with water to within a fifth or sixth part of an inch from the lower orifice of the quill; then applying his mouth to the upper part, he drew the air out of the quill, and in one draught of his breath drew in about a spoonful of water; and this he was able to repeat, the quill remaining as before. The water, he adds, did not ascend to his mouth in a stream, as it would have done had the quill reached the water, but broken, and confusedly mixed with the air which ascended with it. The usual phenomena of water-spouts are exactly agreeable to this theory. They appear at a distance like an inverted cone, or the point of a sword, which is owing to the water rising in large drops at the first, and being expanded as it ascends; and a cloud is generally suspended over the body of the phenomenon. The water which is taken up is undoubtedly salt at the first, but by the rarefaction in the superior regions, it un-

* Philad. Transf. vol. ii.

dergoes

dergoes a kind of natural diſtillation, and loſes all the heavy ſaline particles with which it was charged. Water-ſpouts have been obſerved at land, of which two very remarkable inſtances are recorded in the Philoſophical Tranſactions. Other phenomena have been remarked, which can be explained upon theſe principles only. Accounts have been given of red and yellow rain, of frogs and tadpoles, and even ſmall fiſhes, having been rained upon the tops of houſes. The red and yellow rain was, I apprehend, compoſed of the bloſſoms of vegetables, or of inſects, taken up by one of theſe aerial tubes; and the frogs and fiſhes were probably a part of the contents of ſome pond, in which the water-ſpout originated, or over which it might have paſſed in its perambulation.

The point or cone of the water-ſpout is generally oblique, depending on the force and direction of the wind which drives it along.

Dr. Perkins, of Boſton, whom I had occaſion to mention, when treating of hurricanes, in a paper publiſhed in the ſame volume of American Tranſactions, is diſpoſed to adopt a different theory of water-ſpouts. Captain Melling informed him, that in a voyage from the Weſt India Iſlands to Boſton, a water-ſpout came acroſs the ſtern of the veſſel where he then was, a flood of water fell upon him with ſuch violence as almoſt to beat him down, and the ſpout immediately paſſed off with a roaring noiſe into the ſea. The water from the ſpout, he remarked, was perfectly freſh.

Dr.

Dr. Perkins adds several other instances, on the testimony of mariners, who all affirmed, that they saw the water *descend* from the cloud through the water-spout into the sea, contrary to the opinion of Mr. Oliver, that it always ascends.

A whirlwind, therefore, in the opinion of Dr. Perkins, cannot be the cause of a water-spout; nor can both of these phenomena proceed from the same cause. A whirlwind, he supposes to be produced by the ascent of the heated or rarefied air into or through the colder regions of the atmosphere above. Now, Dr. Arbuthnot says, that the rarefaction of the hottest day renders the air but one-tenth lighter than it is in the coldest.

This roaring noise also, as remarked by Captain Melling, does not agree with the theory of the ascent of water in the spout, as it is not very clear why such a noise should accompany the simple ascent of water.

To determine the matter, it is to be wished, that future observers would be careful to remark, 1st. The incipient state of a water-spout, and in particular, whether any cloud is seen hovering over the part in which it commences; and 2dly, whether the conical part seems gradually to descend from the body of the cloud *.

A tornado seems to partake much of the nature of the two preceding phenomena, but is more vio-

* Philad. Transf. vol. ii.

lent

lent in its effects. It commences very ſuddenly, ſeveral clouds being previouſly drawn together, when a ſpout of wind, proceeding from them, ſtrikes the ground in a round ſpot of a few rods or perches diameter, in the courſe of the wind of the day, and proceeds thus half a mile or a mile. The proneneſs of its deſcent makes it rebound from the earth, throwing ſuch things as are moveable before it, but ſome ſideways or in a lateral direction from it. A vapour, miſt, or rain deſcends with it, by which the path of it is marked with wet.

The gentleman, who furniſhes the above general deſcription, gives an account of one which happened a few years ſince at Leiceſter, about fifty miles from Boſton, in New England, 'It happened in July, on a hot day, about four o'clock in the afternoon. A few clouds having gathered weſtward, and coming over head, a ſudden motion of their running together in a point being obſerved, immediately a ſpout of wind ſtruck the ground at the weſt end of a houſe, and immediately carried it away with a negro man in it, who was afterwards found dead in the path of it. Two men and a woman, by the breach of the floor, fell into the cellar; and one man was driven forcibly up into the chimney-corner. Theſe were preſerved, though much bruiſed; they were wet with a vapour or miſt, as were the remains of the floor, and the whole path of the ſpout. This wind raiſed boards, timbers, &c. A joiſt was found on one end, driven near three

three feet into the ground. The ſpout probably took it in its elevated ſtate, and drove it forcibly down. The tornado moved with the celerity of a middling wind, and conſtantly declined in ſtrength till it entirely ceaſed.'

CHAP. XII.

OF THE HEAT OF THE ATMOSPHERE AND IGNEOUS VAPOURS.

Objects of Meteorology as a Science.—Partly anticipated.—Temperature.—Heat of the Earth.—Effects of the Sun's Rays on different Mediums.—Difference with respect to Temperature between Land and Water.—Effects of Clouds on the Temperature.—Of Evaporation.—Unusual Cold, how produced in Summer and Winter.—Aqueous Meteors.—Igneous Meteors.—Fire Balls.—Shooting Stars.—Ignes Fatui.

METÉOROLOGY, in its moſt extenſive ſenſe, would embrace a large ſcope of ſcience. It includes every thing that concerns our atmoſphere, climate, temperature, vapours, fogs, dew, rain, hail, ſnow, the igneous vapours, as proceeding from inflammable air, and even thunder and lightning, and all thoſe phenomena which are produced by what is termed natural electricity.

The arrangement adopted in theſe volumes, which was the cleareſt that ſuggeſted itſelf to my mind, neceſſarily excludes many of theſe ſubjects. The electrical phenomena have been already treated of, and the theory of rain, ſnow, &c. as adopted by the electrical philoſophers, has been briefly explained; and what remains to be ſaid on aqueous meteors will be more properly introduced in the book

book which is dedicated to the ſubject of *water*, and will be better underſtood when the properties of that fluid are more fully explained.

The phenomena, which preſent themſelves for our immediate conſideration, will therefore be thoſe which are, ſtrictly ſpeaking, aerial or atmoſpherical. The temperature of the atmoſphere will therefore, with propriety, be conſidered, and the igneous meteors with which it is occaſionally charged, and of which the air appears not only to be the vehicle but the pabulum.

The variations of temperature which we experience are chiefly produced in the atmoſphere, or at no great diſtance from the ſurface of the earth. This is evident from a ſimple and well known fact; that the earth, at a certain depth beneath the ſurface, always preſerves nearly the ſame temperature, and the degree of heat at thoſe depths generally approaches the mean annual heat of the climate. Even where there is a communication with the external air, the earth, at the depth of 80 or 90 feet, commonly varies but little in its temperature; and where there is no ſuch communication the variation muſt be ſtill more inconſiderable. Thus the temperature of ſprings does not vary with the ſeaſon; and thus the cave of the obſervatory at Paris, which is about ninety feet below the pavement, preſerves the conſtant temperature of about 53 degrees, never varying above half a degree in the coldeſt years. Van Swinden has remarked, that the moſt extreme cold, even exceeding 0 in Fahrenheit's ſcale, if it endures for only a few days, penetrates no further than twenty inches, even when the ground is not covered with ſnow, and not more than ten inches when there is a coat of ſnow on the ſurface of the earth.

The earth may, therefore, be conſidered as the great repoſitory of heat; but when its ſurface is rapidly cooled, the interior parts experience a diminution of their heat in ſome meaſure proportionable, as the heat is in that caſe drawn off towards the ſurface. Hence in Switzerland it has been remarked, that the ſnow generally begins to melt at the bottom; and if the heat of the ſun is not ſtrong, the ſame thing may be obſerved in the progreſs of a thaw in this country.

The ſurface of the earth is capable of receiving a great acceſſion of heat from the ſun's rays. But it has been before remarked, that light has not the ſame effect on a tranſparent medium, for theſe mediums afford a free paſſage to the rays of the ſun, which appear to act only as fire, when accumulated and confined within the minuteſt interſtices of bodies. Hence the tops of high mountains are always, even under the equator, covered with ſnow; and hence at a certain height, which varies in almoſt every latitude, it freezes during the night in every ſeaſon, as was ſtated in a preceding chapter.

Heat is obſerved to diminiſh as we aſcend into the atmoſphere, nearly in an arithmetical proportion. In the vicinity of Paris, lat. 48° 50′ the temperature of the earth being 47°, at the eſtimated height

height of 11,084 feet, it was found by M. Charles, the aeroſtatical adventurer, to be at 21° or 11° below congelation; near Dijon, lat. 47° on the 25th of April, the temperature near the earth was 56°, but at the height of 10,631 feet, it was found by M. Morveau to be 26°; and Lord Mulgrave, at the bottom of Hacklyt Hill, lat. 80°, found the temperature of the lower air 50°; but on the ſummit of the hill, 1503 feet, only 42°.

Water reſembles air in being little affected by the paſſage of the ſun's rays; but the bottom of every ſea or lake, being opake, the heat is ſtill capable of being excited and collected there. Between water and earth there is, however, this difference, that land or earth (particularly if dry) receives heat very readily from the rays of the ſun, but conducts it through its own ſubſtance very ſlowly to any great depth; whereas water, from its tranſparency, receives heat from light but ſlowly; but the heat is diffuſed through the whole maſs with great rapidity. Dr. Hales relates, that in Auguſt, 1724, when the air and the ſurface of the earth were both at 88, a thermometer, placed at only two inches depth in the ground, ſtood at 85, another at ſixteen inches at 70, and another at twenty-four inches at 68. The two laſt preſerved the ſame temperature day and night to the end of the month, and then only fell to 63. On the 26th of October, a thermometer expoſed to the air by the ſame philoſopher, ſtood at 35° 5, but one ſunk two inches in the earth was heated to 43° 85, another

another sunk sixteen inches reached 48° 8, and one at twenty-four inches 50°. He even found, that between the 1st and 2d of November, when the external air was at 27°, a thermometer at twenty-four inches depth stood at 43° 8; but from March to September, the following year, the external air was much warmer than the earth at sixteen inches or two feet; but the season was rainy, and the evaporation being considerable, prevented the earth near the surface from being considerably warmed.

From these experiments it appears, that the surface of the earth may be considerably heated, and yet that the heat shall not penetrate to any considerable depth; it appears also, that the earth parts with its heat with difficulty to the air, and will retain its natural temperature, which is between 40° and 50°, at a very small depth beneath the surface, even when the air is below the freezing point. In water, on the contrary, the heat is not accumulated in a particular part, but is equally diffused through the whole mass, and the temperature, if the surface is extensive, will be more in agreement with that of the atmosphere than with that of the earth. Near Marseilles, Dr. Raymond found the sand frequently heated to 160°, but never found the sea hotter than 77°, and even this degree of heat it appeared to receive chiefly by its communication with the land, for on the 19th of July, 1765, he found that part of the bay, which was next the land, heated to 74°, while the middle was 72°, and the entrance

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only 70°. In winter, he obſerved the earth cooled down frequently to 14° or 15°, but the ſea never lower than 44° or 45°.

It is by the temperature of the atmoſphere that we always judge when we term the weather cold or hot; but the atmoſphere derives the greater part of its heat from its communication with land or water. The rigours, therefore, of the winter's cold are tempered by the heat imparted from the earth itſelf; yet as the earth parts but ſlowly with its heat, and as the ſurface is found to be extremely cool, while the interior parts are heated to the degree of 40 or 50, and as the heat of water is more equally diffuſed, and more readily parted with, it follows that the portion of air, which is incumbent on the ſea, will be of a warmer temperature in the extreme cold of winter than that which is incumbent upon the land.

Iſlands are more temperate than continents, becauſe they participate more of the temperature of the ſea. With reſpect to thoſe countries alſo, which border on the ocean, thoſe which lie ſouth of the ſea, at leaſt in our hemiſphere, will be warmer than thoſe which have the ſea to the ſouth of them, becauſe the winds which would cool them in winter, if they blew over-land, are tempered by paſſing over the ſea, whereas thoſe which lie north of the ſea are cooled in ſummer by the breezes that iſſue from it.

Every habitable latitude muſt enjoy a heat of 60° at leaſt for two months in the year, in order to produce and bring to maturity corn and the other vegetable productions. The quickneſs with which vegetation proceeds in high latitudes is chiefly owing to the long duration of the ſun above the horizon during their ſummer. Dr. Halley, indeed, has proved, that, abſtracting from the intervention of fogs, miſts, and mountains of ice, the hotteſt weather might take place, even under the poles, the duration of the ſun's light compenſating for the obliquity of its direction.

Among the cauſes of the changes of weather in theſe climates, eſpecially with reſpect to heat or cold, we muſt account the circumſtance of the air being charged with vapour. The air, when cloudy, is capable of receiving and retaining more of the ſun's heat, than when clear, for the obvious reaſon, that a tranſparent medium permits thoſe rays to paſs through it, which are intercepted if the medium is thicker and leſs pellucid. Hence a cloudy air is frequently found warmer than the earth, on which it is incumbent. The air is alſo warmed by the condenſation of vapour, and hence the origin of hail, which is rain condenſed by paſſing through air which is colder than that which produced it.

A continuance, however, of cloudy or miſty weather will intercept the ſun's rays from reaching the earth, which will therefore be prevented from receiving its due portion of heat. The winter of the year 1783-4 was unuſually ſevere; and it is to be remarked, that during ſeveral of the summer months which preceded it, where the effect of the sun's rays to heat the earth should have been the greatest, the whole continent of Europe was covered with a kind of fog, supposed to proceed from the smoke of some volcanoes, near Mount Hecla, in Iceland. This fog was of a dry kind, and consequently the sun's rays were incapable of dissipating it; and they were so faint, that in passing through it, when collected in the focus of a burning glass, they would scarcely kindle brown paper *.

A principal cause of the varieties and changes of temperature, and a most powerful agent in producing cold, is evaporation. On this subject it is remarked, first, that in our climates the evaporation is about four times as great between the vernal and autumnal equinox as in the rest of the year. 2dly. Other circumstances equal, it is increased in proportion to the difference between the temperature of the air and the evaporating surface; it is consequently least when they are nearly of equal temperature. The former part of this proposition must be understood with some restriction; for if the air is more than 15° colder than the evaporating surface, there is seldom any evaporation at all, and the air will more frequently, in that case, deposit moisture than receive it. 3dly. The degree of cold produced by evaporation is much greater when the air is warmer than the evaporat-

* See Dr. Franklin's Meteorological Conjectures.

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ing ſurface, than when the latter is the warmer of the two; for in the firſt caſe the dilation of the vapour is increaſed, and in the ſecond, it is checked. The more vapour is dilated, the more fire or heat it abſorbs; and hence it is coldeſt in an exhauſted receiver, where it abſorbs moſt. Hence warm winds, as the harmattan, ſirocco, &c. are more deſiccatory than cold winds. 5thly. Evaporation is always increaſed greatly by a current of air flowing over the evaporating ſurface. Hence a calm day is always better than one in which there is a ſtrong wind *.

From theſe facts, and from what was previouſly remarked on the ſubject of evaporation in the ſecond book, it is plain, that tracts of land which are covered with trees or luxuriant vegetables are much colder than thoſe where there is a leſs ſurface of vegetable matter, ſuch grounds emitting one *third* more vapour, according to ſome experiments of Mr. Williams, than the ſame ſpace would if actually covered with water †. Hence too, a reaſon will evidently be found for that amazing change of climate which a country undergoes by being cleared and cultivated. America is not the ſame country at preſent, either with reſpect to temperature or ſalubrity, as when it was covered with woods.

From the whole of what has been ſtated, it will follow, that a wet ſummer will generally be ſuc-

* Kirwan on Climate, c. i.

† Philad. Tranſ. vol. ii. p. 150.

ceeded by a severe winter, because the cloudiness of the season will prevent the earth from receiving a due portion of heat, and because the increased evaporation will contribute to lessen the quantity already lodged there. Much will, however, depend upon other circumstances, and particularly upon the course of the wind.

Unusual cold in summer is produced—1st. From the long continuance of easterly or northerly winds.

2dly. From frequent and heavy rains, which are followed by a considerable evaporation.

3dly. From a long continuance of cloudy weather, which prevents the earth from receiving a proper portion of heat from the sun.

Unusual cold in winter commonly happens—

1st. From unusual cold or wet in the preceding summer. In January 1709, the weather was uncommonly cold, and it was remarked, that in the preceding June the thermometer was near the freezing point, and the rain considerable *.

2dly. From the immediate effect of heavy rains, followed by easterly or northern winds. This state of things produces cold in any season from the increased evaporation.

3dly. From westerly or southerly currents in the upper regions of the atmosphere, while east or north winds prevail nearer the surface of the earth.

* Derham's Physic. Theol. l. i. c. 3.

4thly,

4thly. From the arrival of Siberian or North American winds. It has been calculated, that westerly winds may arrive in a few days from America; and if the ocean has been previously cooled by northern gales, even these will seem cold to us. The Siberian winds will, if they originate from a lower latitude, seem to us to come from the south-east; and if they originate in a higher latitude, they will appear north-east, because they will be deflected to the south.

5thly. From the descent of a superior stratum of the atmosphere. This happens when a cold wind in the upper regions passes over a country where the lower strata of the atmosphere are specifically lighter.—Hence a low state of the barometer generally precedes extraordinary cold which is produced from this cause *.

On the state of the atmosphere with respect to heat and cold, and still more on the degree of evaporation, all the phenomena of the aqueous meteors of rain, hail, snow, &c. will be found to depend; but these will be treated of with more propriety in another part of these volumes. The igneous vapours are also connected with the same causes, and are in a considerable degree the effects of evaporation; but their materials are different, as well as their effects, though, from their evanescent nature, they are scarcely at present sufficiently understood.

* Kirwan on Climate, c. 15.

As the phenomena which are ſtrictly electrical have been already treated of, the only meteors of the igneous kind, which remain to be conſidered, may be reduced to three claſſes, viz. fire-balls, falling-ſtars, and ignes fatui.

It has been already ſtated, that the atmoſphere is the general reſervoir of thoſe particles which are exhaled from every body which is volatile, or ſubject to evaporation. In ſpeaking of the fire damp in mines it has been ſhewn, that inflammable air will riſe in large quantities, and to a conſiderable height in the atmoſphere. There are alſo ſome phoſphoric matters, which will alſo occaſionally be rendered volatile, and theſe particles are ſupplied in great abundance from all putreſcent ſubſtances, whether animal or vegetable. It has been ſhewn, that hydrogen or inflammable air readily combines with ſulphur, and forms what is called hepatic gas; it will afterwards appear alſo, that it will combine with phoſphorus, and the phoſphorated hydrogen gas thus formed is remarkable for the property of ſpontaneouſly inflaming when it comes into contact with atmoſpherical air. Thus we are furniſhed with ſufficient materials for the formation of all the different appearances that have juſt been enumerated; and though the matter of the meteors themſelves has, for the reaſon aſſigned, never been chemically analized, yet from analogy it is not difficult to judge of their nature and properties.

Thoſe phenomena, which are claſſed together under the general appellation of fire-balls, were divided

vided by the ancients into ſeveral ſpecies, according to the external form or appearance which they aſſumed. They were alſo regarded by them in a much more formidable light than they are by us, as the certain prognoſtics of great and awful events in the moral and political world. Even the philoſophic Cicero ſpeaks of the "ab occidente faces," as the certain harbingers or indications of thoſe bloody ſcenes which in his time convulſed and deſolated the Roman commonwealth.

Under the general name of comets, Pliny enumerates a variety of theſe phenomena. If the fire commences at one extremity of the meteor, and burns by degrees, he terms it, from its form and appearance, a *lamp*, or *torch*; if an extended maſs of fire paſſes longitudinally through the atmoſphere, he calls it a *dart*; and if its length and magnitude are conſiderable, and it maintains its ſtation for any ſpace of time, it is a *beam*; if the clouds ſeem to part, and emit a quantity of fire, he terms it a *chaſm* *; but this laſt appears to be, ſtrictly ſpeaking, an electrical phenomenon, indeed only a ſtrong and vivid flaſh of lightning.

Several inſtances of theſe meteors are recorded by the ſame author. During the ſpectacle of gladiators exhibited by Germanicus, one of them paſſed rapidly by the faces of the ſpectators at noon-day. A meteor of that ſpecies which he calls a beam, he

* Lampades, faces, bolides, trabes, and chaſma cœli. See Plin. Nat. Hiſt. l. ii. c. 25, 26.

adds,

adds, was seen when the Lacedemonians were defeated at sea, in that memorable engagement which lost them the empire of the sea *. He also mentions a sanguineous kind of meteor, a flame as red as blood, which fell from heaven about the 107th Olympiad, when Philip of Macedon was concerting his wicked plan for enslaving the republics of Greece †. He relates, that when he was himself on the watch during the night in the Roman camp, he was a spectator of a similar appearance—a number of resplendent lights fixed upon the palisadoes of the camp, similar, he says, to those which mariners speak of as attaching themselves to the masts and yards of a ship ‡.

In tropical climates these meteors are more common and more stupendous than in these more temperate regions. 'As I was riding in Jamaica,' says Mr. Barbham, 'one morning from my habitation, situated about three miles north-west from St. Jago de la Vega, I saw a ball of fire, appearing to me about the bigness of a bomb, swiftly falling down with a great blaze. At first I thought it fell into the town; but when I came nearer, I saw many people gathered together, a little to the southward, in the Savannah, to whom I rode up, to inquire the cause of their meeting: they were admiring, as I found, the ground's being strangely

* Plin. Nat. Hist. l. ii. c. 25, 26. † Ib. c. 27.
‡ Ib. c. 37.

broken

broken up and ploughed by a ball of fire; which, as they ſaid, fell down there. I obſerved there were many holes in the ground; one in the middle, of the bigneſs of a man's head, and five or ſix ſmaller round about it, of the bigneſs of one's fiſt, and ſo deep as not to be fathomed by ſuch implements as were at hand. It was obſerved, alſo, that all the green herbage was burnt up near the holes; and there continued a ſtrong ſmell of ſulphur near the place for ſome time after.'

Ulloa gives an account of one of a ſimilar kind at Quito *. 'About nine at night,' ſays he, 'a globe of fire appeared to riſe from the ſide of the mountain Pichinca, and ſo large, that it ſpread a light over all the part of the city facing that mountain. The houſe where I lodged looking that way, I was ſurpriſed with an extraordinary light, darting through the crevices of the window-ſhutters. On this appearance, and the buſtle of the people in the ſtreet, I haſtened to the window, and came time enough to ſee it, in the middle of its career, which continued from weſt to ſouth, till I loſt ſight of it, being intercepted by a mountain that lay between me and it. It was round, and its apparent diameter about a foot. I obſerved it to riſe from the ſides of Pichinca, although, to judge from its courſe, it was behind that mountain where this congeries of inflammable matter was kindled. In the firſt half of its viſible courſe it emitted a prodi-

* Ulloa, vol. i. p. 41.

gious

gious effulgence, then it began gradually to grow dim; so that, upon its disappearing behind the intervening mountain, its light was very faint.'

' Meteors of this kind are very frequently seen between the tropics; but they sometimes, also, visit the more temperate regions of Europe. We have the description of a very extraordinary one, given us by Montanari, that serves to shew to what great heights, in our atmosphere, these vapours are found to ascend. In the year 1676, a great globe of fire was seen at Bononia, in Italy, about three quarters of an hour after sun-set. It passed westward, with a most rapid course, and at the rate of not less than a hundred and sixty miles in a minute, which is much swifter than the force of a cannon-ball, and at last stood over the Adriatic sea. In its course it crossed over all Italy; and, by computation, it could not have been less than thirty-eight miles above the surface of the earth. In the whole line of its course, wherever it approached, the inhabitants below could distinctly hear it, with a hissing noise, resembling that of a fire-work. Having passed away to sea, towards Corsica, it was heard at last to go off with a most violent explosion, much louder than that of a cannon; and, immediately after, another noise was heard, like the rattling of a great cart upon a stony pavement, which was, probably, nothing more than the echo of the former sound. Its magnitude, when at Bononia, appeared twice as long as the moon one way, and as broad the other; so that, considering its height, it it could not have been lefs than a mile long and half a mile broad. From the height at which this was feen, and there being no volcano on that quarter of the world from whence it came, it is more than probable that this terrible globe was kindled on fome part of the contrary fide of the globe, in thofe regions of vapours which we have been juft defcribing, and thus, rifing above the air, and paffing in a courfe oppofite to that of the earth's motion, in this manner it acquired its amazing rapidity *.'

Two of thefe meteors appeared in this country in the year 1783, of which a moft particular and truly philofophical account, and ingenious folution, by Dr. Blagden, is publifhed in the Philofophical Tranfactions of the following year; and as his account will apply to many phenomena of the kind, I cannot take any better method to elucidate this part of the fubject, than by prefenting my readers with a fhort abftract of this very curious and learned memoir.

The firft of the two meteors in queftion was feen on the 18th of Auguft, and was, in appearance, a luminous ball, which rofe in the N. N. W. nearly round; it, however, foon became elliptical, and gradually affumed a tail as it afcended, and, in a certain part of its courfe, feemed to undergo a remarkable change, compared to burfting; after which it proceeded no longer as an entire mafs, but was apparently divided into a clufter of balls of different magnitudes, and all carrying or leaving a

* Goldfmith's Hift. Earth, Vol. I. p. 382.

train

train behind, till, having paſſed the eaſt, and verging conſiderably to the ſouth, it gradually deſcended, and was loſt out of ſight. The time of its appearance was about ſixteen minutes paſt nine in the evening, and it was viſible about half a minute. It was ſeen in all parts of Great Britain, at Paris, at Nuits in Burgundy, and even at Rome, and is ſuppoſed to have deſcribed a tract of one thouſand miles at leaſt over the ſurface of the earth. It appears to have burſt and re-united ſeveral times; and the firſt burſting of it which was noticed ſeems to have been ſomewhere over Lincolnſhire, perhaps near the commencement of the fens. This change in the meteor correſponds with the period in which it ſuffered a deviation from its courſe. If, indeed, the exploſion was any kind of effort, we cannot wonder that the body ſhould be diverted by it from its direct line; and, on the other hand, it ſeems equally probable, that if it was forced by any cauſe to change its direction, the conſequence would naturally be a ſeparation of its parts.

The illumination of theſe meteors is often ſo great as totally to obliterate the ſtars, to make the moon look dull, and even to affect the ſpectators like the ſun itſelf. When this meteor was obſerved at Bruſſels, the moon appeared quite red, but when it was paſſed, recovered its natural light. This effect, the Doctor remarks, muſt have depended on the contraſt of colour, and ſhews how large a proportion of the blue rays enters into that light which could even make the *ſilver* moon appear to have an exceſs

of

of red. The body of the fire-ball, even before it burst, did not appear of an uniform brightness, but consisted of lucid and dull parts, which were constantly changing their respective positions, so that the whole effect was to some eyes like an internal agitation or boiling of the matter. By the best accounts that could be procured concerning the height of the meteor, it seems to have varied from fifty-five to sixty miles. In these two last particulars it seems to have wonderfully corresponded with some other phenomena of the same kind.

A report was heard some time after the meteor disappeared, and this report was loudest in Lincolnshire and the adjacent parts, and again in the eastern parts of Kent; the report we may therefore suppose to be the effect of the two explosions of the body, first over Lincolnshire, and afterwards when it entered the continent; a hissing sound was said also to have accompanied the progress of the meteor. Judging from the height of the meteor, its bulk is conjectured to have been not less than half a mile in diameter; and when we consider this bulk, its velocity cannot fail to astonish us, which is supposed to be at the rate of more than forty miles in a second.

The other meteor, which appeared on the 4th of October, at forty-three minutes past six in the evening, was much smaller than the former, and of a much shorter duration. It was first perceived to the northward, as a stream of fire, like the common shooting stars, but large; but presently burst out

into

into that intenſely bright bluiſh flame, which is peculiar to ſuch meteors. It left behind it a duſky red ſtreak of fire, and, except this, had no tail, but was nearly globular. After moving not leſs than ten degrees in this bright ſtate, it became ſuddenly extinct without any exploſion. The height of the meteor muſt have been between forty and fifty miles; and its duration was not more than three ſeconds.

The Doctor is of opinion, that the general cauſe of theſe phenomena is electricity, which opinion he grounds upon the following circumſtances:—1ſt, The velocity of theſe meteors, in which they correſpond with no other body in nature but the electrical fluid. 2dly, The electrical phenomena attending meteors, the lambent flames, and the ſparks proceeding from them, which have ſometimes damaged ſhips and houſes in the manner of lightning; and, added to theſe, the hiſſing ſound, reſembling that of electricity paſſing from a conductor. As a third argument in favour of this hypotheſis, the Doctor remarks the connection of meteors with the northern lights. Inſtances are recorded, where northern lights have been ſeen to join, and form luminous balls, darting about with great velocity, and even leaving a train like fire-balls. The aurora borealis appears to occupy as high, if not a higher, region above the ſurface of the earth, as may be concluded from the very diſtant countries to which it has been viſible at the ſame time. 4thly, The moſt remarkable analogy, the Doctor thinks, is is the courſe of at leaſt all the larger meteors, which ſeems to be conſtantly from or towards the north or north-weſt quarter of the heavens. Of above forty different fire-balls deſcribed in the Philoſophical Tranſactions, twenty are ſo deſcribed, that it is certain their courſe was in that direction; only three or four ſeem to have moved the contrary way; and with reſpect to the remainder, it is left doubtful, from the imperfect ſtate of the relations.

Notwithſtanding the Doctor's ingenious arguments, I cannot, on my own part, ſubſcribe to the opinion, that theſe phenomena are altogether electrical. The duration of the fire-ball, the unequal conſiſtency of the maſs, and ſeveral other points in the narration, ſeem to indicate that its materials were of a leſs rare and evaneſcent nature than the electric fire. The union of phoſphorus and hydrogen in the atmoſphere, will ſufficiently account for the inflammation of theſe maſſes of volatile matter, and their colour will depend on the nature of the compoſition, as is plain from what has been ſaid upon the ſubject of the fire-works produced from inflammable air *.

One inſtance more of this kind of phenomena I ſhall beg leave to mention, particularly as it differs in many reſpects from the preceding; and from its duration, and the ſtrong ſmell which attended the exploſion, it ſeems not to have been the effect of electricity.

* See Chap. V.

On board the Montague, under the command of Admiral Chambers, in lat. 42° 48′. long 9° 3′. on the 4th of November 1749, about ten minutes before twelve, as the author, Mr. Chalmers, was taking an obſervation, one of the quarter-maſters deſired he would look to the windward. On directing his eye that way, he obſerved a large ball of blue fire about three miles diſtance from them; they immediately lowered the topſails, but it came ſo faſt upon them, that before they could raiſe the main-tack, they obſerved the ball riſe almoſt perpendicularly, and not above forty or fifty yards from the main chains, when it went off with an exploſion as great as if hundreds of cannon had been diſcharged at the ſame time, leaving behind it a ſtrong ſulphureous ſmell. By this exploſion the main-top maſt was ſhattered in pieces, and the main-maſt ſent quite down to the keel. Five men were knocked down, and one of them was greatly bruiſed, and ſome other damage of leſs importance was done to the ſhip. Juſt before the exploſion, the ball ſeemed to be of the ſize of a large millſtone.

The ſhooting or falling ſtar is a common phenomenon, but though ſo frequently obſerved, the great diſtance, and the tranſient nature of theſe meteors, added to the entire conſumption of their materials *, have

* It is a vulgar notion, that the ſmall maſſes of white jelly, which are ſometimes found in the fields, are produced from the falling ſtars, and it is called ſtar jelly. This jelly, however, is the

have hitherto fruſtrated every attempt to aſcertain their cauſe. It is, however, reaſonable to ſuppoſe, that they are intrinſically the ſame with the larger meteors, as in moſt of their properties they perfectly correſpond with them. If the larger meteors are formed from any mixture or combination of inflammable air with phoſphorus, or any other ſubſtance, the ſhooting ſtars are probably the ſame. If, on the contrary, the larger meteors are electrical, there is equal reaſon for ſuppoſing the ſmaller ones to proceed from the ſame cauſe. Some philoſophers, indeed, repreſent both as maſſes of electricity, at ſo great a diſtance that their angular velocity is not ſufficient to prevent the eye from diſcerning their ſhape. There are, however, three reaſons which operate againſt this hypotheſis. 1ſt, The height of theſe meteors is frequently above that to which clouds aſcend, and clouds are the common atmoſpherical conductors of electricity. 2dly, They do not proceed from a cloud, as flaſhes of lightning uniformly do. And, 3dly, There is no noiſe reſembling that of thunder at their firſt emiſſion or appearance; the noiſe in the large meteors only takes place when the maſs ſeparates or goes off like a ſky-rocket, and in this caſe the effect is ſimilar to that of gunpowder, or any diſploding body.

Concerning the nature and compoſition of the *ignis fatuus*, or will-o'-the-wiſp, there is leſs diſpute;

the excrement of the heron, bittern, or ſome animal of the crane kind, which feed on aquatic animals, and have peculiar organs of digeſtion.

the generality of philofophers being agreed, that it is caufed by fome volatile vapour of the phofphoric kind, probably the phofphoric hydrogen gas. The light from putrefcent fubftances *, particularly putrid fifh, and thofe fparks emitted from the fea, or fea-water when agitated in the dark, correfpond in appearance with this meteor. Sir Ifaac Newton defines the *ignis fatuus* to be "a vapour fhining without heat;" and it is ufually vifible in damp places, about dunghills, burying grounds, and other fituations, which are likely to abound with phofphoric matter.

A remarkable *ignis fatuus* was obferved by Mr. Derham, in fome boggy ground, between two rocky hills. He was fo fortunate as to be able to approach it within two or three yards. It moved with a brifk and defultory motion about a dead thiftle, till a flight agitation of the air, occafioned, as he fuppofed, by his near approach to it, occafioned it to jump to another place; and as he approached, it kept flying before him. He was near enough to fatisfy himfelf, that it could not be the fhining of glow-worms or other infects—it was one uniform body of light.

M. Beccaria mentions two of thefe luminous appearances, which were frequently obferved in the neighbourhood of Bologna, and which emitted a light equal to that of an ordinary faggot. Their motions were unequal, fometimes rifing, and fome-

* This fubject will be more amply treated of in the fucceeding Book, under the title Phofphorus, Book VIII.

times

times ſinking towards the earth; ſometimes totally diſappearing, though in general they continued hovering about ſix feet from the ground. They differed in ſize and figure; and, indeed, the form of each was fluctuating, ſometimes floating like waves, and dropping ſparks of fire. He was aſſured there was not a dark night in the whole year in which they did not appear; nor was their appearance at all affected by the weather; whether cold or hot, ſnow or rain. They have been known to change their colour from red to yellow; and generally grew fainter as any perſon approached, vaniſhing entirely when the obſerver came very near to them, and appearing again at ſome diſtance.

Dr. Shaw alſo deſcribes a ſingular *ignis fatuus*, which he ſaw in the Holy Land. It was ſometimes globular, or in the form of the flame of a candle; and immediately afterwards ſpread itſelf ſo much, as to involve the whole company in a pale inoffenſive light, and then was obſerved to contract itſelf again, and ſuddenly diſappear. In leſs than a minute, however, it would become viſible as before, and run along from one place to another; or would expand itſelf over more than three acres of the adjacent mountains. The atmoſphere at this time, he adds, was thick and hazy.

In a ſuperſtitious age we cannot wonder that theſe phenomena have all been attributed to ſupernatural agency; it is one of the nobleſt purpoſes of philoſophy, to releaſe the mind from the bondage of

 imaginary

imaginary terrors; and by explaining the modes in which the Divine Providence diſpoſes the different powers of nature, to elevate our thoughts to the *one* firſt cauſe; to teach us to ſee "God in all, and all in God."

Chap. XIII.

OF THE PROGNOSTICS OF THE WEATHER.

Imperfect State of this Branch of Science.—Prognoſtics of Weather from the previous State of the Seaſon.—From the Undulations of the Atmoſphere.—From the Barometer.—From Fogs.—From Clouds.—From Proſpects.—From the Dew.—From the Sky.—From the Moon.—From the Wind.—Remarks on Water and Wood.

A METHODICAL arrangement of meteorological phenomena, by which more certain prognoſtics of the weather might be procured, is a great deſideratum in the ſcale of uſeful knowledge. That philoſophers have already a conſiderable acquaintance with the nature of heat, water, and air, their numerous and ingenious experiments ſufficiently prove; but when theſe three ingredients of nature are in a compound ſtate floating round our globe, and producing all thoſe various agitations and combinations, known under the general denomination of weather, then their knowledge ſeems to be without ſyſtem, without certainty, and contrary to the very end of true philoſophy, almoſt without utility. From the combination of air and water with heat, from their circulation and their decompofition, arifes all that variety of weather of which the atmofphere of all countries, and particularly that of iflands, is fo fufceptible. It is well known, that water exhales from the furface of the earth in the form of a rare, invifible, expanded vapour, and that after it has been difperfed in the air, and fufpended in it for fome time in that ftate, it is afterwards condenfed into mifts and clouds, and afterwards, when collected into drops, it defcends in rain, hail, or fnow, to the earth whence it originally proceeded, to be there re evaporated and circulated again through the atmofphere.

The atmofphere itfelf is influenced and modified by the variations of its denfity; by its humidity; by the precipitation of the aqueous particles into rain; by the wind; by the power of electricity; and by the agency of heat and cold, as remarked in the preceding chapter.

Though the fcience of predicting the weather is at prefent vague and imperfect, becaufe it is but lately that accurate obfervations have been made on the changes of the weather, yet from what we may collect from the works of De Luc, De Sauffure, Marfhall, and Kirwan, we are authorized to expect fome fuccefs in thofe inquiries. But it can hardly be fuppofed that their obfervations, in the prefent ftate of fcience, will be fufficient to form a perfect theory, till feconded by thofe of fucceeding times. For this falutary ſalutary end it will be neceſſary to make as many obſervations on the different ſigns of the weather as poſſible, ſince it is only by their combination and concurrence, that uncertainty can be removed.

The principal means of predicting the changes of weather, and particularly with reſpect to rain or drought, may be reduced to ſeven, viz. 1ſt. From the preceding ſtate of the weather. 2d. From the undulations of the atmoſphere. 3d. From the barometer. 4th. From the appearance of the clouds. 5th. From the colour of the ſky. 6th. From the wind. 7th. From the moon.

I. As the cauſes of every change of weather muſt have preceded for ſome time the effect, it is in general by an attention to its previous ſtate, that we are enabled to form the moſt accurate judgment of what weather is to be in future expected; from a ſeries of obſervations made from 1677 to 1789, Mr. Kirwan lays down the following rules or principles.

1ſt. When there has been no ſtorm before or after the vernal equinox, the enſuing ſummer is generally dry, at leaſt five times in ſix.

2d. When a ſtorm happens from an eaſterly point either on the 19th, 20th, or 21ſt of March, the ſucceeding ſummer is dry, four times in five.

3d. When a ſtorm ariſes on the 25th, 26th, or 27th, of March, and not before, in any point, the ſucceeding ſummer is generally dry, four times in five.

4th.

4th. If there ſhould be a ſtorm at S. W. or W. S. W. on the 19th, 20th, or 22d, the ſucceeding ſummer is generally *wet*, five times in ſix.

Mr. Kirwan adds, that it rains leſs in March than in November, in the proportion of ſeven to twelve. It generally rains leſs in April than in October, in the proportion of one to two; leſs in May than September, in the proportion of three to four. When it rains plentifully in May, it generally rains but little in September; and the contrary. A week is accounted wet when it contains four wet days, or more; a month, when it contains three wet weeks; and a ſeaſon, or quarter of a year, when it contains two wet months. He terms that a *wet* day in which rain falls to the amount of one pound troy, in the ſpace of a ſquare foot.

In any given year, the probability of a *dry* ſpring is in the proportion of twenty-two to ſix wet, and thirteen variable. Of a *wet* ſummer it is twenty to ſixteen dry, and five variable. Of a variable autumn, nineteen to eleven of wet or dry. That is, out of forty-one years the ſpring in twenty-two will be dry, &c.; and ſo in proportion *.

II. Among the various means of prognoſticating the weather, remarked by the late Mr. Adams †, one of the moſt important, in his opinion, ſeems to be that undulating motion, or diurnal tumult in the air, which is kept up by the heat of the ſun. The

* Mem. Royal Iriſh Acad. Vol. v.

† Diſſertation on the Barometer.

humidity

humidity raiſed from the earth by the heat of the ſun, is ſuſtained in the atmoſphere by its heat, and the agitation of the air. Though this motion is not always viſible to the naked eye, yet by the help of a good teleſcope it becomes eminently conſpicuous; every object appears to be in violent agitation, and the boundary line of the ſenſible horizon, which would otherwiſe be clear and well defined, is waved like a field of corn agitated by the wind, or the ſurface of the ſea in a freſh gale. While theſe undulations continue in the air, the vapours remain there; but when the ſun departs, and they ſubſide, theſe aqueous particles become condenſed, and deſcend to the ground during the night, and in the morning aſſume the appearance of dew.

III. The greateſt acquiſition, perhaps, that ever was made to natural philoſophy, with reſpect to aſcertaining the changes of the weather, was the diſcovery of the Barometer. The nature and uſes of this inſtrument have been previouſly deſcribed *. It is evident, that when the mercury riſes in the tube, the preſſure, weight, or denſity of the air muſt be augmented; but the relation that exiſts between this preſſure and the change of weather, which does not take place ſometimes till ten or twelve hours afterwards, ſtill remains to be explained.

The preſſure of the air upon the reſervoir of the barometer proceeds in general from its weight, and ſometimes from its elaſticity. It has been proved,

* See this Book, Chap. IX.

that

that theſe two properties of air ſometimes vary, and, conſequently, the preſſure which they produce. Whenever the air diſſolves a great quantity of water, its ſpecific gravity is increaſed; the column of air which reſts upon the reſervoir of the barometer becomes heavier, and the mercury riſes. If the ſolution is not perfect, the tranſparency of the air will be diſturbed; hence a kind of miſt will be produced, which will generally cauſe the mercury in the barometer to riſe; but if the ſolution is perfect, the tranſparency of the air will be complete, and fine weather return, as the mercury in the barometer predicted by its aſcent. While certain cauſes determine this water, which is held in ſolution, to deſcend into the lower region of the atmoſphere, before it is ſufficiently condenſed to be regularly formed into rain, there is another part of it which will have previouſly arrived at the ſurface of the earth. As a proof of this, it is obſervable, that when the weather is about to change to rain, all bodies which are impenetrable to water, ſuch as bars of iron, hard ſtones, &c. are found to be moiſt or wet. The column of air which preſſes upon the reſervoir of the barometer, will become, therefore, lighter by the loſs of that portion of water already arrived at the earth; and the barometer will deſcend, and predict the rain, which will come in a ſhort time after, being formed by the remainder of the water, which will then have had time to be formed into regular drops *.

It muſt be confeſſed, that there are ſome appearances which ſeem to contradict this explanation.

* Briſſon. Vol. i.

It

It ſometimes happens, that the barometer riſes even during rain, while the air diſcharges itſelf of the water which it held in ſolution: it alſo happens frequently, eſpecially in the winter, that, during whole months, every time that the mercury riſes in the barometer, rain continues to fall; and every time that it deſcends, fine weather returns. Still this may be reconciled to what has been ſtated; for as (as has been already obſerved) it is the great quantity of water diſſolved in the air which augments its weight, if, therefore, during rain, a new ſolution of water ſhould by any means be effected in greater abundance than the quantity which falls (and this we know may happen from various cauſes) the barometer will riſe. If the water ſo diſſolved remains in the lower region, this riſe of the barometer will predict a freſh fall of rain, which often happens in ſuch caſes. In ſhort, if the air diſſolves a great quantity of water, and at the ſame time cold, or ſome other cauſe, ſhould impede that water from diſſolving perfectly, and riſing to a great height, it will augment the weight of the air in a proportionate degree, and will cauſe the barometer to riſe; and in the mean time it will be ready to be collected into drops, and formed into rain, which will ſoon after take place. While this rain continues to fall, if there is no new ſolution effected, the air will become lighter; the barometer will fall; and, notwithſtanding that, it will predict fine weather, which, according to this rule, ought to happen. That kind of relation which appears to ſubſiſt between the weight

weight of air and the change of weather, according to circumstances, may be accounted for, therefore, in this manner. Fine weather may happen, notwithstanding the diminution of the weight of air, when some other elastic fluid, lighter than it, becomes intermixed with it, without taking away the transparency. In short, the elasticity of air, the force of which may vary from different causes, will still contribute to vary its pressure. This elasticity acts sometimes in conjunction with the weight, so as to increase the effect of it; at other times it acts in a contrary way, and may also diminish, or even counterbalance, the effect of the augmentation of weight. It follows, then, that fine or bad weather may continue, however high the mercury may be in the barometer; and still this does not weaken the explanation which has before been given of this fact.

Observation, however, in these cases is always preferable to theory; and from long and attentive observation, and from a careful inspection of those of other philosophers, Mr. Adams was enabled to lay down the following principles in his useful treatise on this instrument.

1. It generally happens, that, when the mercury in the tube falls, the air being lighter, it will deposit its vapour, and produce rain: but when it rises, the air being heavier, the vapours will be supported, and fine weather is the usual consequence.

2. When the mercury falls in frosty weather, either snow or a thaw may be expected; but if it rises

rifes in the winter with a north or eaft wind, it generally forebodes a froft.

3. It is neceffary to attend to the progrefs of the rife and fall; thus, if it finks flowly, the rain may be expected to be of fome continuance. In the fame manner, when the mercury rifes gradually, we may be inclined to believe, that the fine weather will be lafting.

4. When the barometer is fluctuating, rifing and falling fuddenly, the weather may be expected to be like it, changeable.

5. When it falls very low, there will be much rain.

6. But if its fall is low and fudden, a high wind frequently follows.

7. When an extraordinary fall of the mercury happens, without any remarkable change near at hand, there is fome probability of a ftorm at a diftance.

8. The barometer will defcend fometimes as an indication of wind only; nor is its rife always a certain fign of fair weather, particularly if the wind is to the north or the eaft.

9. A north-eaft wind generally caufes the barometer in England to rife, and it is generally loweft with a fouth-weft wind.

If the air in foggy weather becomes hotter by the action of the fun alone, the fog generally diffipates, and the air remains ferene; but if the barometer falls, and the change of temperature is from a fouth or fouth-weft wind, the fog rifes and forms into clouds, and its afcent is generally a fign of rain.

"We

"We have," says Mr. Adams, "at present no certain data from observations, whereby certain conclusions may be formed relative to fogs, and their connection with rain."

In winter, when the cold decreases suddenly, rain may be expected; but in summer, a sudden increase of heat forebodes rain.

IV. Several prognostic signs of the weather may be collected from the various appearances of the clouds; when they appear to dissolve suddenly into air, and become invisible, it may be considered as a strong indication of fair weather; but, on the contrary, when they seem to form themselves into masses from the surrounding air, and to increase in density and magnitude, rain may reasonably be predicted.

Upon the approach of heavy rain every cloud rises larger than the preceding one, especially so when a thunder-storm is near, when small fragments of clouds collect, and in a little time cover the whole face of the sky. Fishermen, by this rule, frequently prognosticate a storm, from a small point of a cloud appearing on the visible horizon at sea.

When the clouds appear like fleeces, deep and dense towards the middle, and white at the edges, with a bright blue sky about them, either hasty showers of rain, hail, or snow, may be expected.

Mr. Jones, in his philosophical disquisitions, says, that he predicted a high wind forty hours before it began, from the complexion of a single cloud, with white edges, and dark diverging lines from it; after this appearance there was a great ſtorm, which laſted for two days and two nights.

When the clouds, as they come forward, appear to diverge from a point in the horizon, a wind may be predicted, either from that or the oppoſite quarter.

When the ſky is covered with clouds above, and there are ſmall black fragments of clouds, like ſmoke, flying underneath, rain is generally near, and frequently laſting.

The moſt certain ſign of rain is two different currents of clouds, eſpecially if the lower current flies faſt before the wind; when two ſuch currents appear in hot weather, they forebode a thunder-ſtorm.

The inhabitants of the Alps, when diſtant objects appear diſtinct and well defined, and when the ſky appears of a deep blue, ſuppoſe it a deciſive ſign of rain, though no other ſign of it may appear. The blue colour of the ſky in any country is certainly occaſioned by a quantity of vapour equally diffuſed through the air at the time.

Mr. Adams obſerves of the dew, that, when it appears plentifully upon the graſs after a fair day, another fair day may be expected; but if after ſuch a fair day there is no dew upon the ground, and no wind ſtirring, it is a ſign that the vapours aſcend, and that there will be an accumulation above, which muſt terminate in rain. When the dew, or hoar froſt, abounds at an unuſual ſeaſon, and the barometer is low, it is in general a ſign of rain.

V. As the *sky* indicates the state of the vapours in the atmosphere, its *colour* may be considered as an index to the weather.

When the vapours, which appear red in the evening, are dispersed, the sky in the morning in general becomes clear; but when they continue to float in the atmosphere, the morning sky becomes red also, and rain frequently follows.

When a lowring redness spreads far upwards from the horizon, whether in the morning or evening, it is succeeded frequently by either rain or wind, sometimes by both.

When a redness in the sky extends towards the zenith in the evening, the wind may be expected to proceed from the west, or south-west, accompanied with rain in considerable quantity. Perhaps one of the most certain signs of fine weather is the loftiness of the canopy of the sky.

As the rays of light which pass from the sun, moon, or stars, to the earth, are certainly affected in their colour by the state of the vapours through which they pass, those colours may be considered as indications of the quantity and nature of those vapours.

When the clouds in the east, about sun-rise, appear of a gay orange colour, it is generally, and not improperly, supposed to be a sign of rain.

VI. The first of Roman poets, and not the last of natural philosophers, Virgil, observes, that a pale moon is a sign of rain; that a red one forebodes wind; and that when ſhe wears her own natural whiteneſs, with a ſerene ſky, it is a ſign of fair weather.

Mr. Jones, in his phyſiological diſquiſitions, ſays, that when it rains during a moon, the following change will probably produce clear weather for a few days, and then a continuation of rain; but on the contrary, when it has been fair throughout, and it rains at the change, the fair weather will probably be reſtored about the fourth or fifth day of the moon, and continue as before. This gentleman adds conſiderable weight to this obſervation, by aſſerting, that he has made hay after theſe prognoſtics for twenty years, without having once had the mortification to ſee it damaged by rain. I muſt, however, confeſs, that the reaſon of the fact is not clear to my mind; and I therefore give it ſolely upon his authority, and recommend it to future obſervers to confute or confirm it by accurate obſervations.

VII. A whiſtling, howling wind has been generally eſteemed almoſt an infallible ſign of rain.

Mr. Adams, in the diſſertation which has been quoted, has preſented us with ſome uſeful obſervations on warm and cold weather. Living vegetables, ſays he, have a conſiderable effect in altering climates and affecting the weather. Woody countries are much colder than thoſe that are open and cultivated. As a proof of this hypotheſis, Guiana is commonly adduced, of which only a part has been cleared from wood ſince the beginning of this century; the heat in that part is already become exceſſive; whereas, in the woody parts of the ſame country the inhabitants are obliged to light a fire every night.

It is alſo juſtly obſerved, that water abounds moſt in woody countries; that the pureſt ſprings are generally found beneath the friendly ſhelter of a grove; and that in proportion as the woodlands in any country are cleared, the watercourſes are diminiſhed.

Hence may be inferred the neceſſity of preſerving trees about thoſe places whence water-ſprings diſcharge their currents, if it is an object to preſerve them; and alſo of improving ſmall ſprings, by planting trees around them, and eſpecially oaks.

And hence, alſo, it is a fair concluſion, that in this climate, where the cold certainly predominates, woody ſituations cannot be wholeſome; and that, adjacent to houſes eſpecially, the land ſhould be laid open.

CHAP. XIV.

AEROSTATION.

History of Aerostation.—Discovery of Air Balloons by M. M. Montgolfier.—First Balloon exhibited at Annonay.—Balloon filled with inflammable Air exhibited at Paris.—Pilatre de Rozier ascends in a Balloon.—First Balloon exhibited in England.—Ascent of M. Lunardi.—Voyage of M. Blanchard and Dr. Jefferies across the Channel.—Unfortunate Catastrophe of M. M. de Rozier and Romain.—Mr. Baldwin's Description of the Prospect from a Balloon.—Principles of Aerostation.—Modes of filling Balloons.—Use to which they have been applied.

WHEN the principles of natural philosophy are confined to theory only, they may amuse and instruct the inquiring few, without exciting either the curiosity or admiration of the multitude; but when those theories are reduced to practice, and illustrated by experiments, it becomes then more generally interesting, and attracts the attention of the most uninformed minds. Perhaps the principles upon which the air balloons are constructed might be among the amusing speculations of a Boyle or of a Newton, but the actual exhibition of those aerial machines was reserved to awake the curiosity, and excite the astonishment, of the present age *.

Mr.

* Boyle and Newton were certainly so far acquainted with the general properties of air, as to observe, that smoke and heated air would ascend; and we have already observed, in treating

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The Hon. Henry Cavendiſh, in the year 1766, diſcovered that inflammable air was at leaſt ſeven times lighter than common air. Soon after this it occurred to Dr. Black, that if a bladder, ſufficiently light and thin, was filled with this air, as the maſs would be ſpecifically lighter than the ſame bulk of common air, it would neceſſarily riſe in that fluid. A few years afterwards Mr. Cavallo made ſome experiments on this ſubject, and to him belongs the honour of bringing the ſuggeſtion of Dr. Black firſt into public notice, in a paper which was read to the Royal Society on the 20th of June 1782. He found that the thinneſt bladders were too heavy, and that China paper was permeable to the inflammable air; he proceeded therefore no further than blowing up ſoap-bubbles with inflammable air, which aſcended rapidly to the ceiling of a room, and broke againſt it, and theſe may be termed the firſt inflammable air balloons which were ever exhibited.

While the art of aeroſtation was thus on the point of being diſcovered in Britain, M. M. Stephen and Joſeph Montgolfier, paper manufacturers at Annonay, in France, diſtinguiſhed themſelves by exhibiting an aeroſtatic machine of conſiderable magnitude *.

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of the diſcoveries made upon air, that Van Helmont, a diſciple of Paracelſus, gave the name of *gas ſylveſtre*, to that ſpecies of air which was ſeparated from terreſtrial bodies by means of fermentation, &c.

* The principle upon which the aerial machines of Meſſrs. Montgolfier were conſtructed was that of air rarefied by heat, by

After various inferior experiments, a grand one was made at Annonay, on the 5th of June, 1783, before a great multitude of ſpectators. A flaccid bag was ſuſpended on a pole thirty-five feet high; ſtraw and chopped wool were burnt under the opening at the bottom; the vapour, or rather ſmoke, ſoon inflated the bag ſo as to diſtend it in all its parts, and this immenſe maſs aſcended in the air with ſuch rapidity, that in leſs than ten minutes it reached the height of ſix thouſand feet. It was carried in a horizontal direction to the diſtance of ſeven thouſand ſix hundred and ſixty-eight feet, and then deſcended gently on the ground.

The true cauſe of the aſcent of theſe machines is, the air being rarified and expanded within them by the application of heat.

Theſe experiments were no ſooner communicated to the philoſophers of Paris, than it occurred to them, that as the weight of inflammable air was not more than the eighth or tenth part of that of common air, a balloon might be inflated with this light air, which would anſwer all the purpoſes of thoſe of M. Montgolfier, with ſeveral additional advantages. They conſtructed a globe of luteſtring, which was made impervious to the incloſed air by a varniſh of elaſtic gum diſſolved in ſpirits or eſſen-

by which it became expanded, and therefore diſpoſed to aſcend into the common air. As in various other philoſophical experiments, ſo in this of the two brothers, *accident* offered her precarious aid, and they had the judgment to make a proper application of a caſual diſcovery.

tial oil. On the 23d of Auguſt, 1783, they began to fill a globe of thirteen feet diameter with inflammable air; on the 27th of the ſame month it was carried to the Champs de Mars, and being diſengaged from the cords, it aroſe in two minutes to the height of three thouſand one hundred and twenty-three feet. When this balloon went up, its weight was thirty-five pounds leſs than the ſame bulk of common air.

The firſt perſon who aſcended into the atmoſphere in one of theſe machines was M. Pilatre de Rozier. On the 15th of October, 1783, this adventurer went up from a garden in the Fauxbourg St. Antoine in Paris, in a balloon of the Montgolfier kind, or thoſe inflated by heat or rarefied air; its diameter was about forty-eight feet, and its height about ſeventy four; he aſcended from amidſt an aſtoniſhed multitude to the height of eighty-four feet from the ground, and there kept the machine afloat during four hours and twenty-five minutes by repeatedly throwing ſtraw and wool upon the fire. It then deſcended to the ground, and the intrepid adventurer aſſured the ſpectators, that he had not received the leaſt inconvenience during his aerial excurſion.

The firſt balloon was exhibited in England on the 25th November, 1783, in the Artillery-ground, London, by Count Zambeccari, an ingenious Italian. It was launched from that place at one o'clock in the afternoon, and at half paſt three was taken up near Petworth, in Suſſex, forty-eight miles

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from London. It therefore went nearly at the rate of twenty miles an hour, and its deſcent was occaſioned by a rent ſuppoſed to be the effect of the rarefaction of the inflammable air, when the balloon aſcended to the rarer part of the atmoſphere.

The firſt aerial navigator, however, who amuſed the intelligent, and aſtoniſhed the uninformed, of this country, was Vincent Lunardi, a native of Italy; his balloon was about thirty-five feet diameter; the air for filling it was produced from zinc, by means of a diluted vitriolic acid. He aſcended from the Artillery-ground at two o'clock, on the 15th of September, 1784. His balloon firſt took the direction of north weſt by weſt, but it ſoon fell into a current of air which carried it nearly north. At ten minutes paſt four he deſcended on a meadow near Ware, in Hertfordſhire: during the courſe of his voyage the thermometer was as low as 29°, and the drops of water which adhered to the balloon were frozen.

I was myſelf a ſpectator of the flight of M. Lunardi, and I muſt confeſs I never was preſent at a ſight ſo intereſting and ſublime. The beauty of the gradual aſcent, united with a ſentiment of terror on account of the danger of the man, and the novelty and grandeur of the whole appearance, are more than words can expreſs. A delicate woman was ſo overcome with the ſpectacle, that ſhe died upon the ſpot as the balloon aſcended; ſeveral fainted; and the

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ſilent admiration of the anxious multitude was beyond any thing I had ever beheld.

The moſt daring of all aerial voyages, however, was that performed on the 7th of January, 1785, by M. Blanchard and Dr. Jeffries, acroſs the Straits of Dover to France. At about one o'clock, the balloon was launched near the high cliff in that vicinity; the ballaſt was all thrown out except three bags of ten pounds each; there being but little wind their progreſs was very ſlow; they deſcribed the proſpect which they had of the ſouthern coaſt of England as extremely delightful; and they were able to count thirty-ſeven villages. Perceiving the machine to deſcend, they threw out at ſeveral times all their ballaſt, books, &c. and at about twenty-five minutes paſt two, they had a moſt enchanting proſpect of the French coaſt. 'We threw away,' ſays Dr. Jeffries, 'our only bottle, which, in its deſcent, caſt out a ſteam like ſmoke, with a ruſhing noiſe, and when it ſtruck the water, we heard and felt the ſhock very perceptibly on our car and on the balloon.' At length they paſſed over the high lands between Cape Blanc and Calais, when the machine roſe to a greater height than it had reached during the whole voyage. They deſcended in ſafety among ſome trees in the foreſt of Guiennes. In conſequence of this voyage, the king of France preſented M. Blanchard with a purſe of 12,000 livres, and granted him a penſion of 1,200 livres a year.

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The art of navigating through the air made ſo rapid a progreſs, that within two years from its firſt diſcovery more than forty different perſons performed the experiment without any material injury; and it may be juſtly queſtioned, ſays M. Cavallo, whether the firſt forty perſons who truſted themſelves to the ſea in boats or veſſels eſcaped ſo ſafe. We muſt, however, conclude this account of aerial travellers by a melancholy fact, the fate of the gallant Rozier (who had been the firſt aerial navigator) and of his companion, M. Romain.

This unfortunate experiment was undertaken with a view of diſcovering a method of raiſing or lowering aeroſtatic machines at pleaſure. For this purpoſe a ſmall balloon with rarefied air was attached to the larger one, which was filled with inflammable air. The ſmall montgolfier was placed at a proper diſtance beneath the larger one, and it was ſuppoſed, that by increaſing or diminiſhing the fire in the lower machine, the abſolute weight of the whole would be proportionably diminiſhed or augmented.

On the 14th of June, 1785, theſe gentlemen aſcended in the machine, prepared as has been related. They had not been long in the air, when the balloon, filled with inflammable air, was ſeen to ſwell very conſiderably, and the aeronauts appeared very anxious to open the valves, and facilitate their deſcent, by letting the inflammable air eſcape. The whole machine was ſhortly after obſerved to be on fire, at the height of about three quarters

quarters of a mile from the ground. The ſilk, which compoſed the inflammable balloon, was about a minute after perceived to collapſe, and the apparatus deſcended with ſuch rapidity that both of the gentlemen were killed. M. P. de Rozier appeared quite dead when he reached the ground; M. Romain was found with ſome ſigns of life, but expired almoſt immediately after.

This dreadful cataſtrophe ſeems to have contributed to put an end to theſe experiments. Mr. Baldwin, of Cheſter, however, aſcended from that city in the month of September, in the ſame year, and has publiſhed a very accurate and curious account of his obſervations during his voyage. In his aſcent he obſerved, that the loweſt bed of vapour neareſt the earth appeared like pure white clouds in detached pieces, which ſeemed to increaſe as he roſe. They preſently coaleſced, and formed, as he ſays, 'a ſea of cotton, tufting here and there by the action of the air in the undiſturbed part of the clouds.' The whole ſoon became an extended white floor of cloud; above which, at great and unequal diſtances, he obſerved a vaſt aſſemblage of thunder clouds, each parcel conſiſting of whole acres in the denſeſt form; he compares their form and appearance to the ſmoke of cannon, only denſer, and ſomewhat reſembling vaſt maſſes of ſnow. Some clouds had motions in ſlow and various directions, forming a ſcene upon the whole truly ſtupendous and majeſtic.

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The principles on which balloons ascend in the atmosphere will, after what has been stated, be easily understood. It is a well known rule in hydrostatics, that when a body is immersed in any fluid, if its weight is less than an equal bulk of that fluid, it will rise to the surface, but if heavier it will sink, and if equal it will remain in the place where it is first stationed. On this principle, smoke or vapour ascends in the atmosphere, and heated air in that which is colder. That heated air will ascend is easily proved, by bringing a red-hot iron under a scale of a balance, which will instantly ascend, because the hot air, being lighter than that which is colder, ascends, and strikes the bottom, and impels it upwards; but as the density of the atmosphere decreases, on account of the diminished pressure of the superincumbent air, and the elastic property which it possesses, at different elevations above the earth, an air balloon can rise only to a height in which the surrounding air will be of the same specific gravity with itself. When it is in this situation, it will either float, or be carried in a direction with the wind or current of air which it may happen to encounter in those upper regions.

The whole theory of aerostation depends upon this principle; for the same effect is produced, whether we make the air lighter, by introducing heat into it, or inclosing a quantity of *gas* lighter than the common air; both will ascend on the same principle. Philosophers have found by experiments, that a cubic foot of air weighs about five hundred

hundred and fifty-four grains, and that it is expanded by every degree of heat marked on Fahrenheit's thermometer, about one five-hundredth part of the whole; by heating, therefore, a quantity of air to five hundred degrees, we double its bulk when the thermometer ſtands at 54° in the open air, and conſequently its weight will be diminiſhed in the ſame proportion.

With reſpect to the mode of inflating a balloon with heated air, nothing more is neceſſary than the injection of heat into the machine, by burning combuſtibles under it. The air for filling the inflammable air-balloons may be obtained in ſeveral ways; but the beſt methods are, by applying acids to certain metals, or by expoſing a quantity of water with certain mineral ſubſtances, in a cloſe veſſel, to a ſtrong fire. M. Lavoiſier, for this purpoſe, made the ſteam of boiling water paſs through the barrel of a gun kept red-hot by burning coals. Dr. Prieſtley recommends a tube of red-hot braſs, filled with ſmall pieces of iron. By this method inflammable air is produced, the ſpecific gravity of which is to that of common air as 1 to 13.

The beſt varniſh for coating the ſilk of the balloon, in order to retain the inflammable air, is that uſed by M. Blanchard, which conſiſts of elaſtic gum, or caoutchouc, cut ſmall, and boiled in five times its weight of oil of turpentine, the ſolution being afterwards boiled for a few minutes with drying linſeed oil. This varniſh muſt be uſed warm. An aperture, with a valve, to which is attached a cord, a cord, muſt be left in the top of the balloon, to prevent its burſting, by too great inflation, in the higher regions, where the air is leſs denſe.

The only practical uſe hitherto diſcovered for balloons, is that to which the French engineers have applied them in the preſent war, which is, by raiſing them to a convenient height, to enable the engineer to reconnoitre the camp of the enemy, or a fortified place, ſo that he can direct the attack to that part which is moſt eaſily aſſailed.

That ſo curious an invention ſhould, however, terminate here, it is not eaſy to believe. The curioſity of the public has for the preſent been ſatiated; and the few accidents which have happened have diminiſhed the ſpirit of adventure. The difficulty, indeed, of regulating the courſe of theſe aerial machines ſeems an almoſt inſurmountable bar to their general utility. But who will preſume to ſet bounds to the ingenuity and courage of man? The firſt mortal, who committed himſelf to the waves on a miſhapen raft, had probably no ſuſpicion of even thoſe trivial improvements which were ſoon to ſucceed; and the art of navigation was long known, before the mariners compaſs enabled the daring but ſcientific genius of a Columbus to traverſe the vaſt expanſe of the Atlantic ocean.

END OF THE FIRST VOLUME.

ERRATA.

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