THE

ECONOMY OF NATURE

EXPLAINED AND ILLUSTRATED

ON THE

PRINCIPLES

OF

MODERN PHILOSOPHY.

BY

G. GREGORY, D.D.

AUTHOR OF

ESSAYS HISTORICAL AND MORAL, &c.

IN THREE VOLUMES.

WITH FIFTY-SIX PLATES.

The SECOND EDITION, with conſiderable Additions.

VOL. I.

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ADVERTISEMENT

TO THE SECOND EDITION.

THE favourable reception which this work has experienced from the public having rendered a ſecond edition neceſſary ſooner than was expected, but little time has been afforded for new diſcoveries in philoſophy; yet the additions and alterations in this edition will be found conſiderable, and I flatter myſelf they will be thought improvements.

A very long chapter has been added on the Mechanic Powers, and two whole chapters on the Reflexion and Refraction of Light, intended to make the ſcience of optics plain and intelligible to readers unacquainted with mathematics.

Whatever of novelty has occurred in ſcience ſince the firſt publication of the work has been carefully added; many omiſſions have been ſupplied; and by the kind attention of ſeveral ſcientific friends, ſome errors, which had eſcaped in the firſt impreſſion, have been corrected.

G. G.

Chapel-ſtreet, Bedford-row;
Feb. 1798.

TO THE

LORD BISHOP OF LANDAFF.

MY LORD,

IT is ſeldom of much conſequence to be informed concerning the circumſtances which have ſuggeſted any literary undertaking. If, however, it is not a ſubject of curioſity to the public, it is at leaſt of gratitude to me, that it was the peruſal of your Lordſhips two firſt volumes of Chemical Eſſays, that firſt convinced me of the practicability of making philoſophy popular, and induced me to project the preſent publication.

Your Lordſhip will, I fear, diſcover that this is not the ſum total of my obligation to your incomparable work; but that I have freely uſed, and almoſt abuſed, the liberty your Lordſhip was ſo kind as to grant me of extracting from it. In every point of view, therefore, whatever merits the Economy of Nature may be found to poſſeſs, are ultimately to be attributed, not to the author whoſe name appears in the title page; and I can only ſatisfy my own mind by making a public acknowledgment of my obligations, and by ſubſcribing myſelf, with the utmoſt reſpect and ſincerity,

Your Lordship's

Ever grateful Servant,

G. GREGORY.

Chapel Street,
February 1798.

PREFACE

TO THE FIRST EDITION.

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

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 ſubtile 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 theſe ſubjects I have proceeded to what is called the vegetable kingdom, including what is known on the nature and theory of vegetation. The animal economy ſucceeds; and that as little as poſſible might be wanting to complete the courſe of elementary knowledge, I have concluded by a ſketch of the human mind. This latter part will connect properly with my Eſſays Hiſtorical and Moral, publiſhed ſome years ago, and which contain the great outlines of my ſentiments on moral and political philoſophy.

As it was my deſire to make this treatiſe as plain and clear as poſſible to unlearned perſons, I have to apologize to my more ſcientific readers for the occaſional repetition of the ſame principles and obſervations. Having been, in ſome meaſure, all my life engaged in the buſineſs of education, I have ſeen the neceſſity of frequently recalling the attention of young perſons to principles already proved and eſtabliſhed, in order to enable them to underſtand 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.

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, ſince it is intended as an eaſy introduction to general ſcience; and ſince 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, to occupy the life of a man. I might reply by a ſimple fact, that *I never yet have been enabled to gain, by the exerciſe of my profeſſion, a livelihood for myſelf and family*; and it muſt appear a hard caſe to confine the whole attention of any man to what will not furniſh him with the neceſſaries of life; yet the great bulk of my previous publications (without excepting my Eſſays) have been in the direct line of my profeſſion. I do not, however, reſt my apology upon this argument, but I muſt ſay, that in publiſhing the preſent work, I believe I am not leſs eſſentially ſerving the cauſe of religion, than if I had been employed in compiling a treatiſe of divinity. Next to the ſtudy of the ſcriptures, there is none which ſeems to lead the human mind ſo directly to a knowledge of its Creator, as the ſtudy of nature. In an age therefore when atheiſm is publicly profeſſed by ſome, and privately but ſeduloully diſſeminated by others, I cannot but hope that a work like the preſent may have ſome good effects; and though I have not, like an eminent philoſopher of the clerical profeſſion, termed it a phyſico-theology, the reader will 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 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 aſſiſtance 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.

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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. Jeffries 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.

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 thoſe things which are objects of our ſenſes are formed.

The term *body* is ſometimes confounded with that of matter; but they are eſſentially different: Body (boꝺiᵹe) 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 conſequenly 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 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 generation of ſtones in the earth, the various phenomena of petrifactions, and a multitude of other facts, contribute greatly, on a fair conſideration, to diminiſh the abſurdity of the alchemiſts, who ſeem chiefly to have reſted on this hypotheſis (*viz.* that all matter was intrinſically the ſame) their hopes of converting the baſeſt materials by the efforts of art into the moſt ſplendid and valuable of ſubſtances.

Mr. Boyle diſtilled the ſame water about two hundred times, and at the end of each diſtillation found a

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

freſh depoſit of earth. M. Margraff repeated the experiment with ſtill greater caution. By means of two glaſs globes, which communicated with each other, he preſerved the water while in the ſtate of vapour from all contact with the air; and on repeated diſtillation, a quantity of earth of the calcareous * kind was depoſited at the concluſion of each proceſs.

The extreme rarity and minuteneſs of the particles into which different ſubſtances may be reſolved, imparts a ſtill greater degree of probability to this hypotheſis; and in general, the more any body can be divided, the ſimpler it appears in its component parts.

We muſt however be cautious of admitting opinions, which are not ſanctioned by the direct teſt of experiment; and however plauſible the opinion, the accurate obſervations of modern philoſophy have ſuggeſted ſome objections to the homogeneity of matter, 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

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* Earth of lime.

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 combinations of a few ſimple principles in different proportions, than that the very oppoſite qualities of ſome of the rareſt and moſt ſubtile fluids, ſhould depend wholly on the different form or modification of the extremely minute particles which enter into their compoſition.

It is proper however to obſerve, that on this ſubject there has hitherto appeared no deciſive experimental proof on either ſide. The imperfection of all human efforts, and perhaps of the human faculties themſelves, have hitherto confined our inveſtigations to the properties of a few ſubſtances, the ſimpleſt which chemical analyſis has been able to obtain, and which for that reaſon are denominated ELEMENTS.

There are ſome properties which are accounted common to all matter, and which from their importance will require to be ſeparately treated of: theſe are SOLIDITY, EXTENSION, and DIVISIBILITY; ATTRACTION, MOTION, and REST.

The quantity of matter which is contained in the whole univerſe may probably be much leſs than common obſervation would lead us to ſuppoſe. The ſublime mathematics of Newton dictated the aſtoniſhing propoſition:

propoſition: 'that the whole globe of earth, nay that 'all the known bodies in the univerſe may, as far as 'we know, be compounded of no greater a portion of 'ſolid matter than might be reduced into a globe of 'one inch only in diameter, and even leſs*!'

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[*] Pemberton's View of Sir I. Newton's Philoſophy, 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 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 have

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* From CLEO, or ELEO, to create.

determined 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,

1. Fire, heat, or caloric; including light and the electric fluid.
2. The baſis of pure, vital, or dephlogiſticated air, the oxygen of the French chemiſts.
3. Hydrogen, or the baſis of inflammable air.
4. Azote, or the baſis of nitrous acid.
5. Sulphur, the baſis of vitriolic acid.
6. Phoſphorus, the baſis of phoſphoric acid.

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* 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.

7. Coal * or Carbon, the baſis 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.

To theſe later mineralogiſts have added,

6. The Scottiſh, or Stronthian earth.
7. The jargonic.
8. The adamantine.

Whether all or moſt of theſe may not be reſolvable into the five principal earths may yet be doubted; and thus far is certain, that all of them are exceedingly ſcarce: the Scottiſh however is the moſt common.

The metals again are ſubdivided into,

1. Arſenic.
2. Molibdena.
3. Nickel.
4. Cobalt.

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* 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.

To this liſt late diſcoveries have added four new ſemimetals, *viz.* Uranite, Sylvanite, Titanite, and Menachanite.—But of their nature little is known: and it is with ſome heſitation that I inſert their names in the vocabulary of ſimple elements.

In the preſent ſtate of natural knowledge, however, moſt of the above may be conſidered as diſtinct elementary ſubſtances, 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, would therefore oblige us to admit in nature, inſtead of eleven, at leaſt forty 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. 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

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

actual

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 depoſited in the pores of the other.

The *diviſibility* of matter is alſo received with limitation by thoſe who contend for the exiſtence of atoms or firſt principles of bodies; ſince, if their exiſtence is admitted, there muſt neceſſarily be ſome parts or portions of matter indiviſible, and conſequently it cannot be admitted as a property inherent in all matter.

The human faculties are loſt in the purſuit, and the human underſtanding in the contemplation of the actual diviſibility of matter. The ſmalleſt animalcula which is brought within our notice by the microſcope poſſeſſes organized parts, blood and other fluids neceſſary

ceſſary for the ſupport of life, yet how infinitely removed are theſe from our inſpection! Some idea, however, may be formed of the aſtoniſhing power of matter in this reſpect, from inſtances which are furniſhed by all the moſt common experiments of philoſophy. A pound of even ſo groſs a ſubſtance as cotton, may be ſpun into a thread upwards of one hundred miles in length *; and Mr. Boyle ſpeaks of a thread of ſilk 300 yards in length, which weighed no more than three grains and a half. This, however, is ſtill ſurpaſſed by the amazing ductility of gold; ſixteen ounces of which would 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

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* Repoſitory, vol. ii. p. 52.

times

times greater than in its fluid form *. A particle 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 com-

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* 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.

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

mon 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 approach in idea the infinite diviſibility of matter *.

It is, on the other hand, next to an abſolute certainty, that the particles of the hardeſt and moſt compact bodies are not in actual contact with each other, ſince all ſuch bodies are known to contract with cold; which could not be the caſe, if their parts were already as cloſe as they could be to each other.

It would be foreign to the deſign of this work to enter into thoſe calculations and demonſtrations by which mathematicians have attempted to prove how matter may be divided to infinity. Let it ſuffice to ſay, that on the principles which have been advanced in the courſe of this chapter, the ſagacity of Newton has demonſtrated, that the leaſt portion of matter may be wrought into a body of any aſſigned dimenſions, how great ſoever, and yet the pores of that body be none of them greater than any the ſmalleſt magnitude propoſed at pleaſure; notwithſtanding that the parts of the body ſhall ſo approximate, that the body itſelf ſhall be hard and ſolid. His manner of demonſtration is this—ſuppoſe the body to be compounded of particles of ſuch figures, that when laid together the pores found between them ſhall be equal in ſize to the particles themſelves; how this may be effected, and yet the body 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

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* If the reader wiſhes to ſatisfy himſelf concerning the nature and animal functions of a variety of theſe wonderful exiſtences, I muſt refer him to my late much valued friend Mr. Adams's excellent Treatiſe on the Microſcope.

matter

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.

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* Pemberton's View, 355.

CHAP. IV.

OF ATTRACTION AND REPULSION.

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

IT has been found by experience, that all matter, of whatever kind, is ſubject to certain general laws; and the principal of theſe are attraction and 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 common operations of nature, and

and is exemplified by a variety of eaſy experiments. Two leaden balls, having each a ſmooth 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, 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

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

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 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.

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* 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 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.

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 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 be diſplaced

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* '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 ſurprized 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, kupſer 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

† Agric. Foſ. L. ix. p. 347.

‡ Brown's Travels, ed. 1687, p. 69.

placed by the addition of an alkali. This ſpecies of attraction is called combination, becauſe the particles of two bodies by thoſe means become ſo intimately united or combined, that they cannot be ſeparated but by the addition of a third body, which has a greater attraction for one of the component bodies that they have for one another, and it is called elective attrac-traction and affinity, from the ſuperior tendency in ſubſtances to unite with certain bodies in preference of others. In all caſes of elective attraction it is neceſſary, that at leaſt one of the bodies ſhould be in a fluid ſtate.

It is evident that all ſolutions muſt be the effect of an elective attraction. By *ſolution* I mean the diſperſion of the particles of a ſolid body in a fluid in ſo equal a manner, that the compound liquor ſhall be perfectly and permanently tranſparent. In this caſe, therefore, it is plain that the particles of the fluid muſt have a ſtronger attraction for the particles of the ſolid body than they have for one another. A ſolid body may indeed, by mere mechanical means, be minutely diſperſed through a fluid, but the compound in this caſe will be opake and muddy, and if ſuffered to remain at reſt, a ſediment will immediately be depoſited. Thus, if chalk or clay is incorporated with water, they will impart to it their peculiar colour, and the fluid

'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 nothing but a 'change of place; and as the copper is precipitated by the iron, 'ſo the iron might be precipitated by pot-aſh, or any other ſub'ſtance which has a greater affinity with the acid of vitriol than 'iron has.' Watſon's Chem. Eſſ. p. 234 to 236.

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 natuturally 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 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 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 †.

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* Kirwan's Mineralogy.

† 'If what has been ſaid relative to cryſtallization be not perfectly intelligible to the reader, I would adviſe him to make the 'following eaſy experiment, which will give him a better notion '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

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

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'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 becomes 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 cryſtals; 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 remainder begins to cool. By repetition 'of this proceſs of evaporation and cryſtallization, we may obtain 'all the ſaltpetre which was at firſt diſſolved, as no portion of it 'can be evaporated with that degree of heat which is uſed in 'evaporating the water.'

Watſon's Chem. Eſſ. p. 90 to 92.

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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 will be imperfectly formed. So nice and critical is the arrangement of the parts in ſonorous bodies, that it is ſaid the ſmalleſt vibration of the air occurring during the operation of caſting a bell, or rather while the metal is ſettling in the mould, even the barking of a dog, will injure the tone †.

III. The attraction of GRAVITATION materially differs from the two preceding ſpecies of attraction, ſince it requires neither the particles of the bodies, nor the bodies themſelves, to be brought into immediate contact, but acts at conſiderable diſtances, and in this reſpect it is analogous to the attraction of magnetiſm and electricity.

The moſt obvious effect of gravitation is the general tendency of bodies to the ſurface, 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 ſuch an immenſe aggre-

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* Jones's Phyſiolog. Diſquiſ. 22.

† Ibid.

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gate of matter, is ſuppoſed to deſtroy the effect of this attraction between ſmaller bodies, by forcibly compelling them to itſelf. The attraction of mountains, however, upon the balls of pendulums has been found, by repeated obſervations, to be very conſiderable *.

The efficient cauſe of this ſpecies of attraction is as much a ſecret as all the other great principles of nature. Some philoſophers have ſuppoſed gravity to be one of the inherent properties of matter; others have aſcribed it to the agency of a ſubtile fluid; while others, with more modeſty, and probably with more truth, have had recourſe to the immediate agency and interpoſition of the divine power.

We are generally on ſure ground when we deſcribe effects. Ignorant as we neceſſarily are of the cauſes or inſtruments by which the ſupreme governor of the univerſe effects his purpoſes, an attentive obſervation will commonly furniſh us with the obvious mode in which they generally take place. What philoſophers term the laws of nature, are no other than the modes or forms in which her operations are uſually effected; and this is preciſely the caſe with what are called the laws or properties of gravitation.

Firſt, It appears that the gravitating force being proportioned always to the quantity of matter, all bodies gravitate from equal diſtances with equal velocity, except prevented or impeded by ſome reſiſting medium. Thus, though a guinea and a feather will not fall to the ground with equal velocity in the open air, becauſe of the reſiſtance 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 ſame inſtant of time: for though the guinea contains conſiderably

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* Nicholſon's Introd. to Nat. Phil. V. i. p. 26.

more of ſolid matter than the feather, and conſequently requires a more conſiderable 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 a body which requires leſs force to put it in motion.

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

It would perhaps have been more correct to have ſpoken of what is commonly called *ſpecific gravity* in treating of the denſities or poroſity of bodies, but the reaſon why it was omitted on that occaſion will preſently be apparent. The truth is, we have no mode of determining the denſity of bodies, but by the firſt of theſe laws of gravitation, which have juſt been noticed. For ſince the force of attraction which nature exerts upon all bodies, is in proportion to the quantity of matter which they contain, it follows of courſe, that if, of two bodies equal in bulk, the one is heavier than the other, that body is poſſeſſed of greater denſity, or contains more matter in the ſame compaſs.

The *ſpecific gravity* is therefore the very ſame thing with the *denſity* of bodies, and has relation to the quantity of ſolid matter which different bodies contain in the ſame bulk. It is alſo called relative or comparative gravity, becauſe we judge of it by comparing one body with another. If bodies are equal in bulk, it is evident their ſpecific gravities may be eaſily determined by a common balance, and hence fluids, or any ſubſtances 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 carefully 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 detertermine 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 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 pe-

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

culiar 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, 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.

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* Prieſtley's Optics, p. 454.

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.

CHAP. V.

OF MOTION AND REST.

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

BESIDES the principles of gravitation and repulſion, there are other laws to which all matter in certain circumſtances appears to be ſubject; theſe are termed by modern philoſophers the *laws of motion*, ſince they relate to that change of place or ſituation of bodies which is denominated motion, to the force which is neceſſary to this effect, and the velocity which is given to moving bodies by the application of this force or power.

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 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

turally 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 †.

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

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* Pemberton's View, p. 29.

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

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.

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

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

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

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 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.

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* Pemberton's View, p 31.

† Enfield's Inſtitutes, p. 12, 13.

CHAP. VI.

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 ferrugineous 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.

The properly magnetic ores are calciform (reſembling a calx or cinder) and are moſtly of a dull browniſh black †. There are reddiſh magnets found in Arabia; but moſt of thoſe in Europe reſemble wrought iron in colour. Their hardneſs is juſt ſufficient to afford ſparks with a ſteel, and they are with difficulty attacked by a file. They differ conſiderably

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

† Kirwan's Min.—and Cavallo on Magnetiſm.

in ſpecific gravity, and ſeem to contain ſeveral ſubſtances beſides iron in their compoſition, ſuch as argillaceous and ſiliceous earth. Mr. Kirwan is of opinion that ſulphur enters into their ſubſtance, as the ore ſmells of it when heated red hot: probably, alſo, they may ſometimes contain nickel, as that metal, when purified to a certain degree, acquires the properties of the magnet.

Natural magnets are found more or leſs in almoſt every iron-mine, of different ſhapes, and of different ſizes. Some old writers mention magnets that would ſwim on water *; theſe were probably ſome light, ſpongy, volcanic ſubſtances, impregnated with iron. In Virginia there is a magnetic ſand, which contains about one half iron. Thoſe magnets which have the fineſt grain poſſeſs the magnetic virtue in the higheſt perfection, and retain it longer than any other †.

The great and well-known properties of the magnet are, 1ſt, its attractive power; 2dly, its polarity, or diſpoſition to conform to the plane of the meridian; 3dly, the property of dipping or inclining to the earth; and laſtly, the power of communicating the magnetic virtues to other ferruginous bodies.

I. Magnets attract clear iron more forcibly than any other ferruginous body. The iron ores are attracted more or leſs forcibly, in proportion as they are impregnated with the metal, and in proportion as it exiſts in a metallic ſtate. The force of the attraction between a magnet and iron will depend in a great meaſure on the weight and form of the iron; but art and obſervation have furniſhed us with no invariable rule in theſe reſpects.

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* They are in general about ſeven times heavier than water.

† Kirwan and Cavallo.

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

As iron is diffuſed in greater or leſs quantities through almoſt all the different bodies of which the univerſe is compoſed, it is eaſy to ſuppoſe that the natural bodies which are ſubject to the magnetic attraction are very numerous. The perfect metals, gold, ſilver, and platina, as well as lead and tin, are however total exceptions; though their calces are a little attracted. Animal and vegetable ſubſtances alſo, though they are known to contain ſmall portions of iron, ſeldom exhibit any diſpoſition to be attracted before combuſtion *; though it is 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 †.

Muſchenbrock, 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.

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* Cav. on Mag.

† Ibid.

At 6 inches 3 grains.
5 ——— 3½.
4 ——— 4½.
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 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,

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* Adams on Magnetiſm, p. 385. † Cav. on Mag. p. 36.

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 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 the poles of the earth are

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* Cav. on Mag. p. 37.

† Adams on Mag. p. 389.

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 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

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* Adams on Mag. p. 387.

† Cav. on Mag.

‡ See Mr. Adams's Eſſay, p. 409.

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 ‡.

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

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* Adams on Mag. p. 444. —Nicholſon's Phil. ii. p. 296.

† Cav. p. 98.

‡ Ib.

§ Enfield's Inſtit. p. 340.

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. This is called the declination of the compaſs. The magnetic needle varies ſometimes to the eaſt, and ſometimes to the weſt; and it varies not only in different places, but even in the ſame place at different times. The declination at London is not the ſame now as it was a few years ago ‡. Nay, ſome very nice obſervations

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* Cav. p. 40. † Ib. p. 43.

‡ The following table ſhews 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° Eaſt, the higheſt variation, from the year 1700 to 1756, was 17° 15′ Weſt; and the leaſt 16° 30′ W. In vations ſeem 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 ſuppoſing the earth a large loadſtone, or at leaſt that a maſs of ferrugineous matter, equivalent to ſuch a loadſtone, is contained within the bowels of the earth, to which all ſmaller magnets muſt neceſſarily conform. Attempts have alſo been made to explain the variation or declination of the compaſs upon ſimilar principles. If the maſs of ferrugineous or magnetic matter which the earth contains is ſuppoſed to act upon all magnetic ſubſtances, and if this maſs is almoſt conſtantly varying its poſition and compoſition by ſubterraneous fires, it is not very difficult to ſuppoſe, that the magnetic needle will be ſubject to conſiderable variations from theſe important movements †.

The magnetic center is the point between the two poles, where the magnet poſſeſſes neither attraction nor repulſion. If, however, a part of a magnetic bar is broken off at either pole, the fragment will ſtill be a complete magnet, having two poles and a center,

In lat. 15° N. and long. 60° W. the variation was conſtantly 5° E. In lat. 10° South, and long. 60° E. the variation decreaſed from 17° W. to 7° 15′ W. In lat. 10° S. and long. 5° W. it increaſed from 2° 15′ to 12° 45′ W. In lat. 15° N. and long. 20° W. it increaſed from 1° W. to 9° W. In the Indian ſeas, the irregularities were greater, for in 1700, the Weſt variations ſeem to have decreaſed regularly from long. 50° E. to long. 100° E. but in 1756 the variation decreaſed ſo faſt, that there was Eaſt variation in long. 80°, 85°, and 90° E. and yet in long. 95° and 100° E. there was Weſt 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 Inſt. Phil.

* Adams on Mag. p. 415, 416.

† Nicholſon's Phil.

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 themſelves to be ſubject to the attraction of the earth; for a magnet, or magnetic needle, when placed ſo as to be able to act according to its 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

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* Cav. 218.

the poles of the earth; and what is ſtill more agreeable to this theory is, that the dipping or inclination of the 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 the magnet. To acquire a very high degree of magnetiſm alſo, the

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* 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.

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, 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

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* Cav. part i. c. 7. † Ib.

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

magnetic

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 ‡.

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

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* Cav. 92. † Ib.

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

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 at the twiſted part, the broken end will be magnetic §.

5thly. Even hard iron tools, when heated by any briſk action, as hammering, filing, &c. acquire an impermanent magnetiſm, and, while warm, attract thin filings, or ſmall portions of iron ‖. This fact, I am inclined to ſuſpect, muſt depend in a great meaſure on the unequal texture of thoſe tools: if we ſuppoſe them to be compoſed of hard and ſoft particles, the latter will eaſily acquire an impermanent magnetiſm.

6thly. Apparently all the three laſt-mentioned effects depend upon preciſely the ſame cauſe; and, perhaps, we may add to theſe, the magnetiſm which

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* Cav. † Adams, and Cav. ‡ Nicholſon's Phil. 292.
§ Adams on Mag. 444. ‖ Rees's Cyclop. art. *Magnet.*

is produced by electricity. If a bar is laid horizontally to the magnetic meridian, and ſubjected to the electric ſhock, whatever may be the direction in which the ſhock enters, that extremity which is pointed towards the north, will be the north pole; and if the bar ſtands perpendicular, it will follow the uſual law of communicated magnetiſm, that is, in this hemiſphere, the end which is next to the earth will be the north pole *. Lightning is the moſt powerful of all natural agents in producing immediate magnetiſm; it will, in an inſtant, render hardened ſteel ſtrongly magnetic, and will invert the poles of the magnetic needle †.

One of the moſt ſingular properties of the magnet is, the increaſe of power which may be added to 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

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* Cav. † Adams on Mag. 398. ‡ Cav. 25.

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 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

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* Cav. 200. † See Cav. p. 30 and 203.

‡ Adams on Mag. 397, 443. § Cav. 35.

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 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 §.

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

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

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.

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

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, that 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 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 *.

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* 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.

CHAP. VII.

OF THE MECHANIC POWERS.

Six ſimple Machines.—The Lever.—The Pulley.—The moveable Pulley.—Of Wheels.—Clockwork.—Beſt Mode of conſtructing the Wheels of Carriages.—The Wheel and Axle.—The Crane.—The Capſtan.—The Crick or Jack.—The inclined Plane.—Motion of Carriages up an inclined Plane, &c.—The Wedge.—The Screw.—The perpetual Screw.

THE ſcience of mechanics may poſſibly be conſidered as in many reſpects foreign to a work, which, as its title implies, was intended chiefly to detail and explain the operations of nature. It muſt be remembered, however, that the action of the mechanic powers is the effect of thoſe laws of motion which have been explained in a preceding chapter, and that even ſome of nature's operations can ſcarcely be well underſtood, without a previous acquaintance with thoſe principles by which bodies are moved with the greateſt facility, and by which the animal machine in particular is enabled to act.

There are ſix ſimple machines or powers, of which all the more complex engines are conſtructed; and theſe are the *lever*, the *pulley*, the *wheel and axle*, the *inclined plane*, the *wedge*, and the *ſcrew*. It has been remarked by ſome authors, that theſe ſix machines may in fact be reſolved into two, the *lever* and the *inclined plane*, for the pulley and the wheel and axle may be conſidered as compound levers, and the wedge and the ſcrew are only modifications of the inclined plane.

I. The LEVER is of all machines the moſt ſimple; it is a bar of iron, of wood, or of any ſimilar material, by means of which a ſmall force applied to one end, aided by a *fulcrum*, or prop, placed at any part between the middle and the other extremity, is capable of overcoming or reſiſting a greater.

There are three kinds of levers. A lever of the *firſt order* is where the prop C (Plate I. fig. 1.) is placed between the moving power * A and the point of reſiſtance B. Upon this plan are conſtructed balances, ſteelyards, and the moſt uſual inſtruments for weighing, as well as the common inſtruments for cutting, &c. as ſciſſars, pincers, ſnuffers, &c.; and ſeveral large but ſimple machines for raiſing weights, drawing water, and other ſimilar purpoſes. A lever of the *ſecond order* is when the reſiſting force B (fig. 2.) is placed between the power at A and the prop at C.: and a lever of the *third order* is when the power at A (fig. 3.) is placed between the weight or reſiſtance B and the prop C.

Theſe may be conſidered as the different kinds of levers, and they admit of a further diſtinction or ſubdiviſion, according as the point of power and the point of reſiſtance are more or leſs diſtant from the prop. For example, in the lever (fig. 4.) if the prop is at *a*, the power at *p*, and the reſiſtance at *r*, it is called a lever of the firſt order with *equal arms*; if the prop is at *b*, it is a lever whoſe arm of power *p*, is to that of the reſiſtance *r*, as two to one; and if the prop is at *c*, the arm of power is to that of reſiſtance as three to one; and the ſame may be applied to the other orders. Thus if the point of power *p*, in a

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* That which moves the lever, or acts upon it.

lever of the *third order* (fig. 5.) is placed at 1, it is then a lever whoſe arm of power *p*, is to that of reſiſtance R, as one is to three; for the length of the arm of the lever is always determined by its diſtance from the prop C. But if the power P, is placed at 2, it is then a lever whoſe arm of power P, is to that of reſiſtance R, as two is to three.

It is the diſtance of theſe forces from the prop which determines the velocity of their motion, which is always in the ſame proportion as the diſtances; for when the prop is at C (fig. 6.) one of the powers at B, and the other at A, double the diſtance from the prop, the latter power A will have a velocity which is double that of the firſt power at B. Becauſe when the lever begins to move, while the point B deſcribes the arch B *b*, A will deſcribe the arch A *a*, which will be double the former, for arches are always in proportion to their *radii* *.

The force of a moving body is the reſult of its maſs multiplied by its velocity, it follows therefore in the firſt place, as has been obſerved above, that a weight acting by a lever produces a force ſo much the greater, as its diſtance is greater from the prop, becauſe then it poſſeſſes greater velocity; ſecondly, it follows that two equal weights, acting in oppoſite directions upon a lever, are not in equilibrio when they are not at equal diſtances from the prop; and thirdly, that two unequal weights, acting upon a lever, will exert equal forces when their diſtances from the prop are in a reciprocal proportion to their reſpective maſſes. Hence it follows, that whatever is gained in power is loſt in time, and the contrary.

In what has been hitherto obſerved of the lever, it

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* The radius is the ſemidiameter of a circle, or that line which proceeds directly from the center to the circumference.

has been preſuppoſed that powers acting upon it have either been in perpendicular directions, or in thoſe of equal obliquity to the arms of the lever.

The moſt advantageous poſition for a power acting by means of a lever is that which is perpendicular to the arm of the lever. As in the inſtance of the lever (fig. 7.) if the power B acts in the direction *b* B, it will exert the greateſt poſſible force; but it will have leſs force if it acts in the directions *b* D or *b* E. When, however, one power is oblique to the arm of the lever, and another power becomes equally oblique by being in parallel directions, as the lines *a p* and *b r* (fig. 8) then they have the ſame relation as before to each other. But if the directions are in different degrees of obliquity, then that which departs moſt from a right angle will have the leaſt force; for example, if the power Q (fig. 9.) preſerves a perpendicular direction, and the other power an oblique one, acting upon the line *p c*, *p d*, *p e*, or *p f*, the latter power then becomes weaker in proportion as it departs from the perpendicular direction *p* P.

From what has been already ſtated, it follows that the power is greater, or leſs, or equal to the reſiſtance, according as the diſtance of the reſiſtance from the prop is greater, or leſs, or equal to that of the power. Hence in a lever of the firſt order, the power may be either greater, or leſs, or equal to the reſiſtance; in a lever of the ſecond order, the power is always leſs than the reſiſtance; and laſtly, it follows that it muſt be greater in a lever of the third order: ſo that this order of lever, ſo far from aiding the power as to its abſolute force, muſt, on the contrary, impede it. Yet it is the lever of the third order which nature moſt frequently employs in the human body *. Thus when

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* See Borelli de motu animalium.

we elevate a weight with the hand, this weight may be conſidered as fixed to the arm of a lever, whoſe prop is at the elbow, and whoſe length is conſequently equal to the diſtance between the elbow and the weight. But this weight is ſuſtained in this ſtate by the action of the muſcles, the direction of which is very oblique to the arm of the lever, and conſequently the diſtance of the moving power from the prop is much leſs than the diſtance of the weight from the ſame prop. Hence the effort of the muſcles muſt in this caſe be much greater than the weight or reſiſtance. To account for this ſtructure, it muſt be remarked, that the nearer a power applied to a lever is to the prop, ſo much the leſs is the ſpace it acts in when it raiſes the weight. Now the ſpace which the power had to occupy was what Providence had moſt to regard in the ſtructure of our bodies. It is on this account that he has placed the direction of the muſcles at a ſmall diſtance from the prop, but he has wiſely made them ſtrong in proportion.

The prop of a lever may be regarded as a third power, which keeps in equilibrio the motive force and the reſiſtance, or which concurs with the one to enable it to ſuſtain the effort of the other.

In a lever of the firſt order, the prop C (fig. 10.) which is placed between the power D and the reſiſtance E, ſupports a force equal to the abſolute weight or effort of the two forces, when theſe forces are applied in a direction parallel to each other, and the force exerted upon the prop C, is in the direction C I parallel to that of the two forces. But if the power I Q (fig. 11.) and the reſiſtance K N are in a direction which inclines them towards each other, the prop L is charged with leſs than the ſum total of the two forces, and leſs in proportion as this inclination is greater, and the force which is exerted upon the prop

prop L, is in the direction L M, which tends to the point of contact M of the two forces.

It would be the ſame if the powers *f* and *g* (fig. 12.) were in equilibrio by the inequality of their diſtances from the prop H, that is, in caſe their maſſes were in an inverſe ratio to their diſtances *f* H and *g* H from the prop. The charge upon the prop can never be greater than the ſum of the two forces, or in other words the ſum of the oppoſed maſſes; but it would be equal to this ſum if the powers were in a direction parallel to each other, and it would be leſs than this ſum if the lines of direction *e c*, *e e* were inclined towards each other, then the force upon the prop H would be exerted in the line H I, which would tend to the point I, where the two maſſes would meet according to the direction in which they act.

In levers of the ſecond and third orders the prop ſupports only a part of the effort of the two forces. In other words, it acts in conjunction with the power in levers of the ſecond order, and in conjunction with the reſiſtance in levers of the third order; as when two men carry a burden with a ſtaff upon their ſhoulders; theſe two men, one of whom may be regarded as the power, and the other as the prop, only carry each a part of the burden; and he who is the neareſt the burden carries the greater ſhare of it, and that in proportion to his nearneſs to it.

II. The PULLEY is a ſmall wheel moveable upon its axis, with the circumference hollowed to receive the cord, which is attached on the one hand to the moving power, and on the other to the reſiſting force. The wheel or pulley is commonly fixed in a block, or caſe, which admits the rope or cord to paſs freely over the circumference of the wheel, and the gorge of the pulley,

Fig. 1.

Fig. 2.

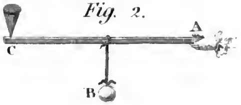


Fig. 3.

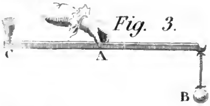


Fig. 4.

Fig. 5.

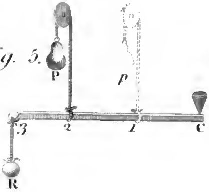


Fig. 6.

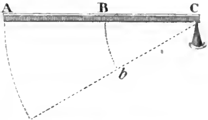


Fig. 7.

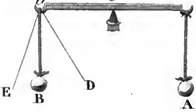


Fig. 8.

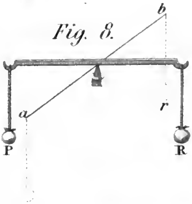


Fig. 9.

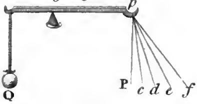


Fig. 10.

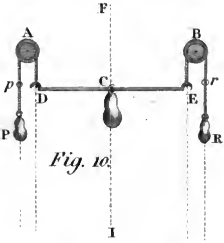


Fig. 11.

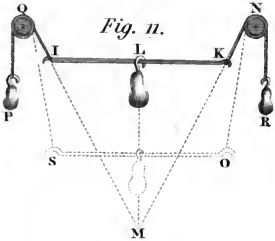
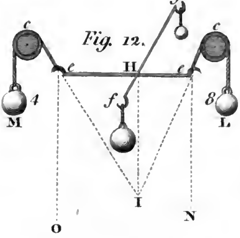


Fig. 12.



ley, that is the hollow part of the circumference which receives the cord is generally hollowed out angularly and not round, ſo that the cord being in ſome meaſure pinched or compreſſed in this angle, it will not be liable to glide or ſlip in its motion.

Pullies are commonly made of wood or metal, and always turn upon an axis. When they are made of wood, it is better to fix the axis to the pulley, and to let all turn together in the ſpace which ſuſtains the pulley. The movement then being performed upon a leſs ſurface will be leſs impeded by friction, and if the ſpace which contains the pulley becomes larger, as it is only the lower part which can be affected; the aperture will be lengthened, the pulley will deſcend a little, but its circular motion will not be diminiſhed; it is not ſo when the pulley turns upon its center, for then if the aperture which receives the axis enlarges, the enlargement is frequently not equal in all its parts.

By means of pullies burdens are elevated with greater eaſe, and in a more commodious manner than they otherwiſe could be; more commodious becauſe the motion is continued, and its direction may be changed ſo as to bring the whole force which is applied to it into immediate action, for by this means a horſe which can only exert his force in an horizontal direction, is able to overcome a vertical reſiſtance. Burdens are moved with more eaſe by pullies, becauſe a great weight may be elevated by a ſmall force properly applied. The power applied to a pulley draws in all directions without impediment, becauſe the cord by which it acts is always a tangent * to the circum-

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* A tangent is a right line drawn perpendicular from the extremity of the radius, which touches the circumference of a circle without cutting it.

ference of the pulley, and conſequently always perpendicular to the radius. The powers applied to pullies act more forcibly in proportion as their diſtance from the axis is greater, whether the cords run in ſeveral groves, or ſeveral pullies of different diameters turn upon the ſame axis; thoſe powers therefore which act at the greateſt diſtance from the axis will have the advantage over the other. Let us ſuppoſe a weight of ſix pounds to be placed at I (Plate II. fig. 1.) there ought then to be ſix pounds at H to ſuſtain it, becauſe the radii *c d* and *c* 1 are equal. But three pounds placed at K will ſuſtain the ſame weight, becauſe the radius *c* 2 is double the radius *c d*; and it requires but two pounds in L, becauſe the radius *c* 3 is treble the radius *c d*.

In all theſe caſes the pulley performs the office of a lever of the firſt order, for it may be conſidered as an aſſemblage of fixed levers, of which the center is the common fulcrum. All theſe levers have equal arms in pullies with one gorge, and they are of unequal arms in pullies of ſeveral gorges. (See fig. 1.) All theſe pullies are fixed.

It has been obſerved, that by means of a pulley of many gorges (fig. 1.) the actions of two unequal powers may be rendered equal; in the ſame manner an equilibrium or a conſtant relation may be preſerved between two powers, the relative forces of which continually change. A pulley may be uſed for this purpoſe, which, inſtead of many concentric gorges, has but one, but that in a ſpiral form, which conſequently augments the diameter by degrees, according to the proportion in which the exceſs of one of the two forces augments. For example, let a pulley A (fig. 2.) have its gorge hollowed in a ſpiral form, of which the hollow is ſeen at *g a b c*, and the plain at *d e* 4; let there be fixed in the center of this pulley a

barrel

barrel *e* or E, furniſhed with a ſpring like that of a watch. If the force of the ſpring is ſuch, that any given power (a weight, for example, acting at D E) keeps it in equilibrium; when the ſpring is rolled three or four rounds more, the ſame weight acting at *g* F will keep it ſtill in equilibrium, if the radius E F is lengthened in proportion to the augmentation of force in the ſpring; what has been obſerved of the point F may be ſaid of all the others. Hence it follows, that theſe two powers, the ſpring and the weight, will always act againſt each other in a certain ratio or proportion, even though the force of either ſhould be occaſionally augmented: It is upon theſe principles that clock and watch-makers are able to calculate the force of their ſprings, weights, and pendulums, and to adapt them with the utmoſt preciſion to the other movements.

The axis *c* (fig. 1.) of a ſimple pulley can never be charged with a greater force than that which is equal to the ſum of the two powers I and H, but it may be ſomewhat leſs. When the directions *b* I and *i* H of two powers are parallel, that is, when the cord embraces half the circumference of the pulley, the axis is charged with a force equal to the ſum of the two powers. But if the direction of the two powers is oblique to each other, the axis is then charged with a leſs force than the ſum of thoſe of the two powers; and in that caſe, the force with which the axis is charged is to the ſum of the forces of the two powers, as the chord of the arch embraced by the chord is to the diameter *d i*; the effort is then made upon the axis *c*, in a direction which, paſſing through *c*, tends to the point of meeting according to the direction of the two powers.

In all theſe caſes the force H muſt be equal to the reſiſtance

reſiſtance I, in order to keep the equilibrium. Hence it follows, that the ſimple pulley neither aids nor hinders the power; it only ſerves, as has already been obſerved, to keep the power in its moſt advantageous direction, to change the direction of the motion, and to render it conſtant.

The pulley may alſo be conſidered as a lever of the ſecond order, for it has all the properties of that machine when the reſiſtance R (fig. 3.) is attached to the neck *c i*, and one of the ends of the cord which paſſes under the pulley is attached to the fixed point *a*, while the other is drawn or ſuſtained by the power *d*: The pulley then becomes what is called a *moveable* pulley, and is elevated with the burden; it conſequently is analagous to a lever of the ſecond order *b e*, of which the fulcrum or prop is at *b*, and is divided into two equal parts *b c*, *c e*, by the direction *c* I of the reſiſtance R; it is on this account only neceſſary that the power *d* ſhould poſſeſs half the force of the reſiſtance R to keep it in equilibrium; and if the burden is elevated, the power *d* acts through twice the ſpace of that of the reſiſtance R, and conſequently with double the velocity: For ſuppoſe the center *c* of the pulley is carried to the point *b*, then there only remains under the line *d a* the portion of the cord which paſſes under the pulley; the two portions *b a* and *e d* have then paſſed above; but *b a* and *e d*, which mark the ſpace run through by the power, are, taken together, double to *c b*, the ſpace run through by the pulley; then the power has a velocity double to that of the reſiſtance. In this caſe the cord embraces half the circumference of the pulley, and the directions of the two powers are parallel. The arm of the lever of power is then the diameter *e b* of the pulley, that of the reſiſtance is only the radius

dius *c b*. Becauſe to keep an equilibrium, it is neceſſary that the power ſhould be to the reſiſtance, as the radius is to the diameter.

But if the direction of the powers is oblique, as for inſtance, if one end of the cord is attached to the fixed point *g*, while the other is ſuſtained by the power P, it ſtill repreſents a lever of the ſecond order *m l*, of which the fulcrum will be at *m*, and which will be divided into two equal parts *m i*, *i l*, by the direction *c* I of the reſiſtance. Then the power P will be to the reſiſtance R as the radius *c b* is to the ſpace *l m* of the arch embraced by the cord.

If inſtead of drawing the cord upwards it is neceſſary to draw it downwards, a fixed pulley *n* (fig. 4.) is placed above the moveable pulley *m*, which makes no change in the effect of the power. And when the power is not ſufficient to elevate the burden, a ſecond moveable pulley is added, and another fixed one (fig. 5.) or even a greater number, by means of which the power has much greater effect. This ſyſtem of pullies, ſome moveable and ſome fixed, and all embraced by the ſame cord, is called by ſome a tackle. The fixed pullies 2 and 4 are ſupported in the ſame neck or caſe, and the moveable pullies 1 and 3 by another neck. The lower part M of the neck, which ſupports the fixed pullies, ſerves as a fixed point for one end of the cord, and it is the lower part R of the neck which ſupports the moveable pullies to which the burden is hung.

By means of this union of pullies, a very great burden may be raiſed by a ſmall force; for it is demonſtrable that the force neceſſary to ſuſtain a weight by means of ſeveral pullies, is to the weight itſelf as unity is to double the number of moveable pullies. When the directions of the cords are parallel to each other,

other, the powers are then (as has been before obſerved) in an inverſe ratio to the velocities.

Hence it follows, that the number of pullies and the power being given, the weight which the ſyſtem of pullies is capable of ſuſtaining is eaſily found, by multiplying the power by double the number of moveable pullies. For example, ſuppoſe that the power is equal to 60 pounds, and that the number of moveable pulies is 3, 60 multipled by 6 (double the number of 3) will be equal to 360, which is the weight that this ſyſtem of pullies is able to ſuſtain.

In the ſame manner the number of moveable pullies being given, as well as the weight which the tackle is able to ſuſtain, the power is eaſily found by dividing the weight by double the number of moveable pullies. Suppoſe the weight equal to 800 lb. and the number of moveable pullies to be 4; 800 divided by 8 (that is, by double the number of pullies) gives the quotient 100 lbs. which is the force neceſſary to ſuſtain 800 lbs. with ſuch an union of pullies *.

To

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* ‘ It may be obſerved, that in all contrivances by which ‘ power is gained, a proportional loſs is ſuffered in time. If one ‘ man, by means of a tackle, can raiſe as much weight as ten ‘ men could by their unaſſiſted ſtrength, he will be ten times as ‘ long about it.

‘ It is convenience alone, and not any actual increaſe of force, ‘ which we obtain from mechanics. This may be illuſtrated by ‘ the following example:

‘ Suppoſe a man at the top of a houſe draws up ten weights, ‘ one at a time, by a ſingle rope, in ten minutes. Let him have a ‘ tackle of five lower pullies, and he will draw up the whole ten ‘ at once with the ſame eaſe as he before raiſed up one; but in ‘ ten times the time, that is, in ten minutes. Thus we ſee the ‘ ſame work is performed in the ſame time, whether the tackle be ‘ uſed or not: but the convenience is, that if the whole ten ‘ weights, To find the number of moveable pullies which are neceſſary to ſuſtain a given weight with a given power, the weight muſt be divided by the power, and then half the quotient will be the number ſought. Suppoſe, for example, the weight to be 500 lbs. and the power 50; the apparatus ought to have 5 moveable pullies, for 500 divided by 50 gives 10 for the quotient, the half of which is 5.

In all theſe caſes it has been preſumed, that the direction of the cords is parallel to each other. If it is oblique, then the burden to be ſuſtained is to the power, as the ſum of the ſines * of the angles, which the cords of the moveable pullies make with the horizon, is to the whole ſine. It follows then, in this caſe, that the power muſt be greater than is required in the former caſe; the direction therefore of the cords ought if poſſible to be always parallel to each other.

To prevent the friction of the ropes one againſt another, which occaſions a conſiderable reſiſtance and wears them much, it has been found neceſſary to employ in a ſyſtem of pullies ſome of a ſmaller diameter, which is inconvenient on account of the ſtiffneſs of the rope. It is therefore better to place the pullies of

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'weights be joined into one, they may be raiſed with the tackle, 'though it would be impoſſible to move them by the unaſſiſted 'ſtrength of one man.

'Or, ſuppoſe, inſtead of ten weights, a man draws ten buckets 'of water from the hold of a ſhip in ten minutes, and that the 'ſhip being leaky, admits an equal quantity in the ſame time. 'It is propoſed, that by means of a tackle, he ſhall raiſe a bucket 'ten times as capacious. With this aſſiſtance he performs it, but 'in as long a time as he employed to draw the ten, and therefore 'is as far from gaining on the water in the latter caſe as in the 'former.' Nichol. Phil. vol. i. p. 74.

* The ſine is the meaſure of an angle, or a right line drawn from the extremity of one leg to that of the other.

each tackle, the upper and the lower, parallel to each other, to place them in a common neck, and to make them move upon an axis common to all, as in fig. 6. all the pullies are then of equal diameters. This kind of tackle is in common uſe, eſpecially on board ſhips. The ropes, however, are not exactly parallel; but this defect is inconſiderable.

In the preceding calculations the reſiſtance produced by friction, and that which ariſes from the ſtiffneſs and weight of the ropes are not regarded, on account of which it is neceſſary to augment the power, and to make it greater than I have ſuppoſed. It may alſo happen, that in augmenting the number of pullies theſe reſiſtances will be augmented ſo much, that they do more than compenſate for the augmentation of the force which reſults from the increaſe of the number of pullies.

Wheels, like pullies, may be conſidered as an aſſemblage of levers. Of wheels there are two kinds: the firſt always turn in the ſame ſpace upon an axis fixed to the center of the wheel, the pivots of which turn in holes or cavities which ſerve as a prop: ſuch are the wheels of clocks, of mills, &c. Theſe kind of wheels receive or tranſmit the movement by teeth, or cogs placed round the circumference.

Wheels of the other kind, that is, which turn upon their circumference, have their center or axle-tree in a direction parallel to the plane on which they move; ſuch are the wheels of waggons, coaches, &c. They have therefore two movements; the one, of their center which advances in a right line, and the other, of all their parts which perform a circular motion round the center.

When wheels of the firſt kind are put into action, it is common to place upon the ſame axle a great wheel

Fig. 1.

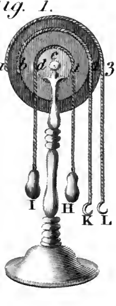

Fig. 2.

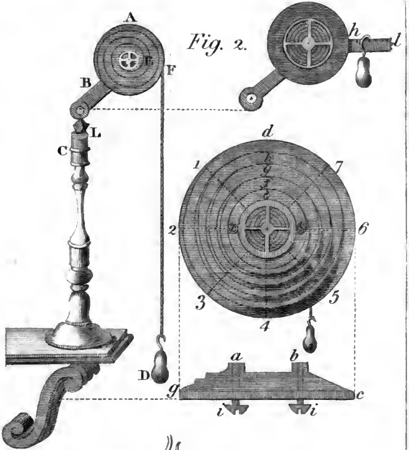

Fig. 3.

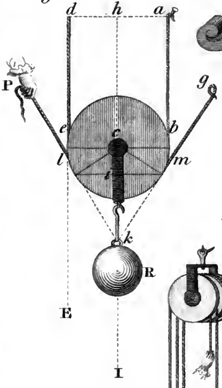

Fig. 4

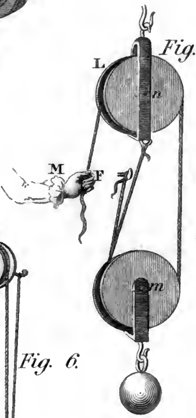

Fig. 5.

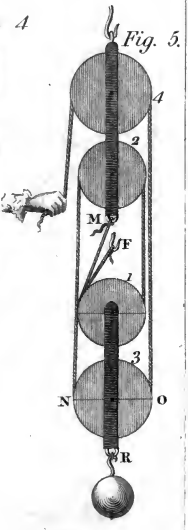

Fig. 6.

wheel and a ſmall one, called a pinion, and ſometimes a *nut*, the teeth of which coincide with the teeth of another large wheel. In large machines, trundles are often ſubſtituted for pinions or nuts, and perform their office; theſe are cylinders or ſpindles parallel to each other, and placed circularly in two plain pieces of wood at the top and bottom. The teeth of the wheel then catch the ſpindles of the trundle as they do the cogs of the nut or pinion. The mechaniſm is the ſame in both caſes: ſo that it ſuffices to examine the manner of hooking or catching of wheels and pinions.

Wheels of the firſt kind, thoſe whoſe motion is confined to the ſame place, may be conſidered as levers of the firſt order; the arms of which are the radii of the wheels and nuts, and which have their prop at the axle. Let A B C (Plate III. fig. 1.) be three wheels, and *a b c* their correſponding pinions or nuts. The nut, or what is the ſame thing, the cylinder *a* ſuſtains the weight P; the wheel A, which has the ſame axle as the cylinder *a*, catches the nut *b*; the wheel B, which has the ſame axle as the nut *b*, catches the nut *c*; the wheel C, which has the ſame axle as the nut *c*, is drawn at its circumference by the power Q: and the whole ſyſtem is in equilibrium. Here the weight P acts by the radii of the nuts; but the power Q acts by the radii of the wheels. Suppoſe the radii of the wheels to be four times thoſe of the nuts; and that the firſt are eight inches, and the other two inches. To preſerve an equilibrium, it is neceſſary that the power ſhould be to the reſiſtance, as the product of the arms of the lever of reſiſtance is to the product of the arms of the lever of power, that is, in an inverſe ratio of the length of the arms of the lever; theſe products are found by multiplying the one by the other, that is, the radii of

the

the wheels and the radii of the nuts. The firſt product will be 512; and the ſecond 8, in which caſe the power Q ought to be to the weight P, as 8 is to 512, or as 1 is to 64. Hence it follows, that to preſerve an equilibrium, whatever is the diameter of the wheels and of the nuts, the power is to the reſiſtance as the product of the radii of the nuts is to the product of the radii of the wheels.

It appears then that this form of machines is capable of giving a great advantage to the force or power over the reſiſtance; but this advantage is neceſceſſarily acquired at the expence of time or velocity; when the machine paſſes from a ſtate of reſt to that of motion. For there is always as much loſt in time as there is gained in force, and ſo reciprocally.

There is often occaſion, eſpecially in clock-work, that the number of the revolutions of the wheels and that of the nuts ſhould bear a certain proportion. This is performed by giving a convenient number of teeth or cogs to the wheels and nuts: as for example, if it was required that a wheel ſhould make only one revolution while a nut ſhould make four, there muſt be four times as many teeth in the wheel as there are cogs in the nut. Suppoſe A B C D (fig. 2.) to be four wheels, the firſt of which A, catches the nut *b* fixed to the ſecond B; this catches the nut *c* fixed to the third wheel C; this third catches the nut *d* fixed to the fourth D; laſtly, this fourth wheel catches the laſt nut *e*; now to obtain the proportion between the number of revolutions of the firſt wheel A, and the number of revolutions of the laſt nut *e*, multiply the number of teeth of the wheel A, by the number of teeth of the wheel B; this firſt product by the number of teeth in the wheel C, and the ſecond product by the number of teeth in the wheel D; then multiply the number of cogs of the nut *b* by the number of cogs in the nut *c*; this firſt product by the number of cogs in the nut *d*; and the ſecond product, by the number of cogs of the laſt nut *e* : the laſt products of the teeth of the wheels and the cogs of the nuts, will give the proportion required.

It may then be eſtabliſhed as a general rule, that the number of the revolutions of the firſt wheel A, is to the number of the revolutions of the laſt nut, as the product of the cogs of the nuts is to the product of the teeth of the wheels. Hence it follows, that it is not neceſſary to determine the number of cogs and teeth which each nut and wheel ſhould have in particular; it ſuffices that the proportion of the product of all the cogs to the product of all the teeth, ſhall be ſuch as is required.

By means of this kind of wheels, the action of a power may be tranſmitted to a diſtance, the direction of the movement may be changed, and the velocity of the powers may be varied.

Firſt, if inſtead of applying the nut (fig. 3.) immediately upon the wheel H, a nut D is fixed to the other extremity of the prolonged axle as far as is neceſſary, then the power which acts by the handle G may be tranſmitted to a certain diſtance by means of the nut D fixed at the extremity of the axle.

Secondly, If this nut D catches with another wheel E, which has teeth parallel to its axle, the movement which will be tranſmitted to it will change the direction, and become horizontal inſtead of vertical.

In fine, if the wheel E has four times as many teeth as the nut D has cogs, ſince the nut cannot move without the vertical wheel H, it follows that the latter muſt turn four times round while the horizontal wheel turns round once; and ſo on the other hand, if this makes one revolution, the nut D and the vertical wheel H will make four in the ſame time. For inſtance, ſuppoſe that to each of the great wheels H and E, a handle G or F is fixed, and turned by a man once in a ſecond, the velocity will be four times as great when he turns by the handle F as if he turned by the handle G. But it is true, that in this caſe he muſt uſe four times the force; becauſe whatever is gained in force is loſt in time; and on the contrary, what is gained in time is loſt in force; yet it is often advantageous to have the liberty of choice.

As to wheels of the ſecond kind, which have two ſorts of motion, as thoſe of carriages, the center of which advances in a right line while the other parts turn round it, they may be regarded as a lever of the ſecond order, the action of which is repeated as often as there is ſuppoſed to be points in the circumference. For each of theſe points is the extremity of a radius C M (fig. 4.) ſupported at one end by the ground M; and the other end C charged with the axle which ſupports the carriage is at the ſame time drawn by the power P which moves it along. So that if the plane was perfectly level, and the circumference of the wheels without any inequalities; if there was no friction between the axle and the nave, and if the direction of the power conſtantly remained parallel to the plane, then a ſmall force would draw a very heavy carriage; for the reſiſtance which proceeds from the weight, reſts entirely upon the ground by the radius or ſpoke C M, or by another ſpoke which immediately ſucceeds. But theſe circumſtances are never or very ſeldom to be found in practice. The wheels of carriages are frequently rounded in a coarſe manner, and large nails driven into them; the roads are uneven, or made ſo by the weight of the carriages which paſs over them. Theſe inequalities, whether of the wheels or of the earth, therefore cauſe the wheel to be ſupported by a radius C Q or C N, oblique to the direction of the power C P, or to the direction of the reſiſtance C M. Then the weight which is ſuppoſed to preſs at C reſiſts the power which cannot make it advance but by cauſing it to riſe as much as the point Q or N is above the point M. The power is then obliged to ſuſtain part of the weight of the carriage, as if it was placed upon an inclined plane. When, moreover, the circumferences roll upon ſurfaces perfectly ſolid and level, there is indiſpenſably a conſiderable friction between the axle-tree and the nave.

The little elevations and depreſſions in roads change alſo the direction of the power. A horſe placed higher or lower, by the diſpoſition of the ground, inſtead of making his effort in the line C P, parallel to the portion of the plane which ſupports the wheels, makes it often by the line C S or C R, that is, obliquely to the direction of the reſiſtance C M, and conſequently with diſadvantage; for a carriage which may be moved eaſily by one horſe only upon a horizontal plane, often requires many horſes to move it up a riſing ground.

In general, the moſt advantageous mode of moving burdens in carriages over rough and uneven ground, as roads are for the moſt part, is, according to Meſſrs. Stevin, Wallis, and Deparcieux, to draw in a riſing line, as C R; for this purpoſe it is neceſſary that the axle of the wheels ſhould be a little lower than the breaſts of the horſes, by which means the direction of the power approaches more to the paralleliſm of each of the ſmall inclined planes which form the inequalities of the roads.

But

But if it is impoſſible to overcome theſe difficulties entirely, they may be prevented in part by employing large inſtead of ſmall wheels. For it is certain, that ſmall wheels entangle themſelves more than great ones in the ruts and hollows in roads, as may be ſeen by the fig. 5, where the radius *c q* of the ſmall wheel, which bears againſt the ground, in riſing out of a hollow in the road, is much more oblique to the direction of the power *c p* than the radius C *q* of the great wheel to the direction C P. As the circumference alſo of a great wheel meaſures, in rolling, more of the road than that of the ſmall one, it turns ſwifter, or makes fewer revolutions, in paſſing over a given ſpace, which ſaves no inconſiderable part of the friction.

III. The WHEEL and AXLE * or *windlaſs*, one of the ſix ſimple machines, is a cylinder which turns upon its own axis, by means of which, with a ſmall force, a great burden may be elevated by a rope which wraps round the cylinder by the aid of a handle, or by means of cogs or bars uſed as levers, acting on the circumference.

It is the common practice to fix at one of the extremities of the cylinder A B (fig. 6.) levers, ſuch as E, F, G, H, by means of which the cylinder is turned upon its axis C D, while the cord which ſuſtains the weight *a*, is wrapped or wound about it. It is eaſy to ſee that the effect of the wheel and axle is analogous to that of a lever of the firſt order. For, ſuppoſe that *h g* (fig. 7.) repreſents the radius of a cylinder, and that *h* P repreſents the arm of a lever, by which the power P acts: if the length of *h* P is to that of *h g* as 3 to 1, a power of 100 pounds at P, acting in a perpendicular direction at P *h*, will balance a weight G of 300 pounds.

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* By ſome called the axis in peritrochio.

Hence

Fig. 1.

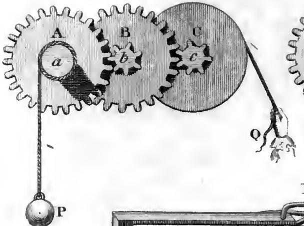


Fig. 2.

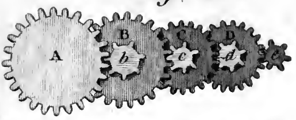


Fig. 3.

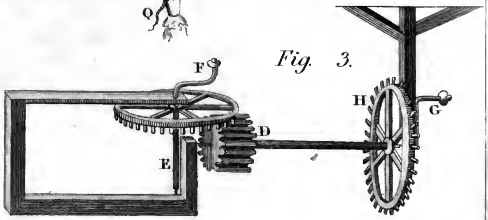


Fig. 4.

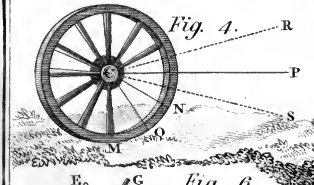


Fig. 5.

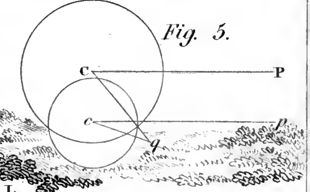


Fig. 6.

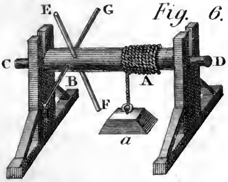


Fig. 7.

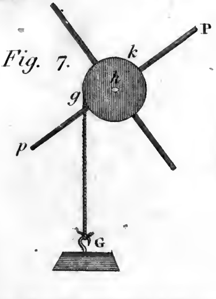
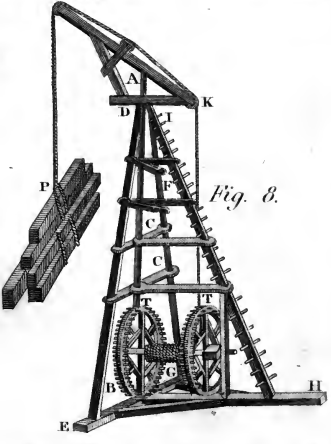


Fig. 8.



Hence it follows, that to elevate a weight by means of this machine, it is required that the power P ſhould be to the weight G, as the radius of the cylinder *hg*, is to the lever *h*P; or, which amounts to the ſame, as the radius of the cylinder is to the radius of any wheel or handle by which it may be turned. If in a ſtate of equilibrium the power is leſs than the weight, and that in the proportion of the radius of the cylinder to that of the handle which turns it, ſo in a ſtate of motion the power has more velocity than the weight, and that in proportion as the radius of the handle or wheel that turns it is to that of the cylinder. This rule ſuppoſes that the power is always perpendicular to the radius by which it acts; for the direction of the weight is always perpendicular to the radius of the cylinder, ſince the cord that ſuſtains it is always a tangent to its circumference.

In great efforts, as it is neceſſary that the arms of the lever of power ſhould be very long; when therefore it is extremely inconvenient to make them ſo, and when to multiply the number of them would weaken the head of the cylinder too much, it has been the practice to unite the extremities of the radii or cogs by a circumference, and form a kind of wheel to which other cogs are adapted, by which it is turned by men; as may be ſeen in the wheels uſed at quarries and for cranes (fig. 8.)

The *capſtan* is a real windlaſs, and it differs only in the poſition of the cylinder, which is vertical, whereas in the windlaſs it is horizontal. The manner of a power acting upon a reſiſtance or burden, by means of a wheel and axle or windlaſs, is entirely applicable to the capſtan, but the latter is more advantageous. Capſtans are often fixed in ſhips, to raiſe anchors or other burdens to which cables are faſtened, which are rolled or coiled upon the cylinder.

It

It is eaſy to perceive that the capſtan acts as a perpetual lever of the firſt or ſecond order with unequal arms; and that the arm of reſiſtance is much ſhorter than that of the power. For the arm of the lever by which the reſiſtance acts, is the radius of the cylinder; and the arm of the lever bv which the power acts, is the ſame radius lengthened by the whole extent of one of the croſs levers.

Ships have often two kinds of capſtans on board; that is, a double capſtan and a ſmall one. The double one is placed upon the firſt deck, and riſes about four or five feet above the ſecond deck, it is deſigned for the more important purpoſes, as to raiſe the anchor, &c. The ſmall capſtan is placed upon the ſecond or third deck between the main and mizen maſts, and ſerves to work the ſails, yards, &c. on different occaſions.

The *crick* or *jack* is another machine by which a great reſiſtance or weight may be overcome by a ſmall force. The ſimple jack conſiſts of a bar of iron A B (Plate IV. fig. 1.) furniſhed with teeth in one of its faces, and moveable in a caſe C E. The teeth of the bar A B coincide with thoſe of the nut D D, which turns upon its axis by means of the handle M N. The action then of the nut protrudes the bar, and conſequently raiſes the weight placed at its head A.

When the effort which each tooth of the nut makes in D to raiſe the bar, is conſidered as a weight applied to a lever, it is clear that the power applied to the handle, is to that weight as the radius of the nut is to the arm of the handle N M. Hence it may be perceived, that by making the radius of the nut very ſmall, in proportion to that of the handle, a very conſiderable weight may be raiſed or moved by a moderate force. A ſmall portable inſtrument of this kind is, I underſtand, commonly employed by the houſebreakers about the metropolis, to force open doors or windows, or to remove locks or whatever obſtructions may be oppoſed to them.

IV. The INCLINED PLANE is that which forms an angle with the plane of the horizon. This angle may be infinitely ſmall, and then it is confounded with an horizontal line; on the contrary, it may be a right angle, and then the plane becomes vertical: between theſe two extremes are comprized all the other degrees of inclination.

The principle on which the whole theory of the inclined plane is founded is this: That the time which a rolling body takes to deſcend upon an inclined plane, is to the time in which it would deſcend vertically by its abſolute gravity from the higheſt part of the plane, in the ratio or proportion which the length of the plane bears to its perpendicular height; a body therefore placed upon an inclined plane is partly ſuſtained by the plane itſelf, and therefore a weight or power conſiderably inferior to that of the body is able to ſupport it in its ſituation on the plane, or even to cauſe it to aſcend. On this account it is that in making reſervoirs for water, trenches in fortification, or in clearing the earth away for the foundations of buildings, the wheel-barrows or other vehicles employed are made to aſcend upon a plank or ſcaffolding, which is placed in the direction of an inclined plane.

To render this part of the ſubject perfectly intelligible, let A C (fig. 2.) be an inclined plane, then to ſuſtain the body D upon this plane, and to prevent it from falling, it is not neceſſary that the weights *d*, *d*, which retain it by means of the cords D *e* *d*, ſhould be (taken together) equal to the weight of the body D, but

but may in fact be conſiderably leſs, if theſe weights *d*, *d*, draw in the direction D *e*, parallel to the inclined plane. But if theſe weights draw in the direction D F or D E, they neceſſarily loſe a part of their force, as will appear from what has been already advanced on the ſubject of obliquity, in treating of pullies, &c.

Hence it is evident, that the power acts to the greateſt advantage when the line of traction, or the line in which the body is drawn, is in the direction D *e*, parallel to the inclined plane. When thus ſituated therefore, there will be an equilibrium, when the power is to the weight of the body, as the height of the plane is to its baſe. In other words, the mechanical advantage gained by the inclined plane is in proportion as the length of the plane exceeds its height*. Thus if a weight of four ounces is laid on an inclined plane, the length of which is to its height as 2 to 1, it will be counterbalanced by a weight of two ounces drawing in the line D *e* (fig. 2.) parallel to the plane; or if the length of the plane is to its height as 4 to 1, the body will be ſuſtained by one ounce only. Hence in drawing a cart or waggon up hill, if the power of the horſes bears the ſame proportion to the weight of the waggon, as the height of the hill to its declivity, then the waggon will not run back, and a ſmall additional force will enable it to advance.

V. The WEDGE, which is alſo one of the ſix ſimple machines, is of a triangular form; the thinneſt part is called the point or edge, and the thicker the head or baſe of the wedge.

The action of the wedge agrees moſt with that of the inclined plane. It is made uſe of to cleave, to

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* Adams's Lectures, vol. iii. p. 295.

raiſe,

raiſe, or to compreſs bodies; and to put it in action the blow or ſhock is commonly given with a hard body, ſuch as a ſledge or hammer, though ſometimes the preſſure of a weight is employed. The reſiſtance which may be overcome by means of the wedge, often depends upon the tenacity of the parts, which is difficult to eſtimate. The percuſſion which puts the wedge into action is alſo difficult to judge of by the effects of preſſure: on this account the theory of the wedge is not ſuſceptible of great preciſion. But approaches may be made to preciſion, by ſubſtituting powers, the abſolute force of which is known, as of weights, and then obſerving what proportion there exiſts between the power and the reſiſtance when a wedge is introduced.

Let us ſuppoſe two rollers *m*, *n*, (fig. 3.) the one *m* attached to the cord *l m e*, and the other *n* to the cord *n i d*, each bearing a weight of 10 lbs. *p* and *r*, and paſſing over the pullies *f* and *h*; and let us ſuppoſe alſo that the baſe *a b* of a wedge is equal to the half of its height *c b*. It will then require a preſſure of 5 lbs. to keep this wedge in equilibrio with the ſum of the two weights, which is equal to 20 lbs, and a little more than 5 lbs. to ſink the wedge its whole depth *c b*, without making any allowance for friction. It is evident by the conſtruction, that while the wedge is ſunk its whole depth *c b*, the two weights *p* and *r* will each riſe one half of *i l*, which is equal to *a b*, the baſe of the wedge. And as it is required, in producing an equilibrium, that the power ſhould be to the reſiſtance in an inverſe ratio to the velocity, or to the ſpace through which two bodies move in the ſame time, it is clear that in this caſe, the power muſt be to the reſiſtance as the half of the baſe is to the height of the wedge. The ſharper the wedge is, therefore,

therefore, that is, the more acute the angle, the more powerful is its action, and the greater the effects which may be produced by the ſame force.

If the wedge is employed to ſplit or to cleave the parts of a hard body which ſtrongly adhere together, its advantage is augmented in proportion as the wedge is ſunk or driven deeper between theſe parts. For ſuppoſe two pieces of wood *ſ q* and *t r* (fig. 4.) firmly connected together by the ſtrong bandages *p*, *u*, *x*, &c. all equal in ſtrength, and which may repreſent the adheſion of the parts of a billet of wood; the wedge being placed between the two billets, acts in ſome meaſure as by the arms *ſ p*, *t p* of two angular levers *ſ p q*, *t p r*, while the two other arms *p q*, *p r* confined by the bandages, mutually ſupport each other. If then the force of the wedge exceeds a little that of the firſt bandage *p*, this bandage will be broken. The ſecond bandage *u*, though as ſtrong as the firſt, will be broken more eaſily by the action of the ſame wedge, becauſe then the arms of the lever by which it acts, are lengthened by the quantity *p u*, and ſo of the others. It is doubtleſs on this account that hard and dry wood, ſtones, glaſs, and in general all bodies which are very ſtiff or inflexible, break with conſiderable noiſe, and cleave or crack upon the firſt effectual attempt to cut them.

All inſtruments deſigned for cutting or ſtabbing, as knives, hatchets, ſwords, punches, &c. are claſſed with the wedge. In ſhort, they have at leaſt two inclined planes, ſometimes four or more, which form among them an angle more or leſs acute; nails, pins, and needles are alſo included in this claſs.

VI. The SCREW is the laſt of the ſix ſimple machines which we have to conſider, and is a long cone or cylinder A B (fig. 5.) upon the circumference of which is cut a ſpiral groove or gorge C F G. The partition C F between the rounds of the gorge is called the *thread* of the ſcrew; and the diſtance C G, which there is between one thread and another, is called the *ſtep* or *pace* of the ſcrew.

The thread and the gorge are fitted ſometimes into a cylindrical cavity made in a piece of metal or wood, which is ſometimes called a ſocket, but more frequently a *female ſcrew*, while the other is named the *male*, or principal ſcrew.

It is eaſy to ſee that the thread of a ſcrew is an inclined plane, at the baſe of the cylinder A B (fig. 5.) The height of this plane is the pace or ſpiral of the ſcrew, or, which is the ſame thing, the diſtance of one thread from another: its baſe is the circumference of the ſcrew, and its length is eſtimated by this circumference and the height of the pace; for if one of the threads *a b* is developed, it will form with its pace *b c*, and its baſe, or the circumference *a c* of the ſcrew, a triangle *a b c*, and a rectangle at *c*, of which it is eaſy to find the ſide *a b*, ſince the two others are known, as well as the angle at *c*: hence by a ſcrew turning in its ſocket they conſtitute two inclined planes ſliding the one upon the other.

The threads of ſcrews aſſume different forms according to the materials of which they are made, or thoſe into which they are to enter, or according to the efforts they are deſigned to make. In wooden ſcrews the threads C, G, F, are generally angular, which add greatly to their ſtrength; for by this form they have a larger baſe upon the cylinder which ſupports them. This form is alſo given to the threads of thoſe ſmall iron ſcrews which are conical, ending almoſt in a point, and which are deſigned to enter into wood, in which they form the ſockets for themſelves. Drills and gimblets may be conſidered as of the ſame nature, the ſpiral points of which enter the wood ſo much eaſier in proportion as they are ſharper at the end. But with reſpect to large metal ſcrews which are uſed for preſſes, vices, &c. their threads are generally made ſquare, in order that the friction may be increaſed by augmenting the ſurface of each thread; for it frequently happens that the principal effect of ſcrews ariſes from the cloſeneſs of the friction: this form hinders the cheeks or chaps of the vice from ſwerving backwards, to which they have a natural tendency by the re-action of the piece which they preſs between them.

Screws are uſed principally for the preſſing of bodies firmly againſt each other, and ſometimes for raiſing weights or burdens, or for forcing backwards or forwards certain maſſes of a determinate quantity. For this purpoſe a male and female ſcrew are made uſe of, one or the other of which ſerves as a *fulcrum* or prop. Sometimes the male ſcrew is fixed, while the female ſcrew is moveable; but in both caſes the effect of the ſcrew is the ſame.

When this machine is made uſe of, one of the two pieces (the male or the female) is applied to the reſiſtance which is to be overcome, and the other ſerves as a fulcrum or prop to the machine; then by the act of turning, the ſocket is made to move upon the ſcrew, or the ſcrew into the ſocket. In ſmiths' vices, for inſtance, one of the cheeks is preſſed, by the action of the ſcrew, againſt the other cheek; it appears, therefore, that the power muſt move one complete round, in order to advance the reſiſtance one pace or ſpiral of the ſcrew, that is, a quantity equal to the diſtance of one thread from

from another. If the power is applied immediately to the ſcrew, the ſpace it paſſes through, or its quantity of motion, is $a\ c$ (fig. 5.) which is the meaſure of the circumference of the ſcrew, and the motion of the reſiſtance is meaſured by $c\ b$, the width of one pace of the ſcrew. But as it is common to turn ſcrews, eſpecially large ones, with levers or ſomething equivalent, in that caſe $a\ c$ does not meaſure the motive force of the power; it is, on the contrary, meaſured by the circumference of the circle, of which the lever D E is the radius. And as it is neceſſary, in order to maintain an equilibrium, that the powers ſhould be in the inverſe ratio of their velocities, it may be eſtabliſhed as a general rule in uſing ſcrews, if we make no account of the friction, that the power is to the reſiſtance as the height of the pace of the ſcrew is to the circumference which the power deſcribes.

The *perpetual* ſcrew differs in many reſpects from that which has now been deſcribed. It is a cylinder, which always turns in the ſame direction, its two extremities A and B (fig. 6.) being carried upon ſolid pivots, ſo that its action is perpetuated, whence it derives its name. The threads $z\ h$ of this ſcrew, which are generally ſquare, coincide with the teeth of a vertical wheel C h, which carries upon its axis a roller or windlaſs T with a cord, to which is faſtened the burden P, which is required to be elevated. A very ſmall force, therefore, applied to the handle M E is ſufficient to raiſe a very conſiderable burden at P, but it requires conſiderable time, from the invariable rule in mechanics, that whatever is gained in force is loſt in velocity.

In order to find the relation between the weight P and the force or power Q, it muſt firſt be conſidered that the weight P is counterbalanced immediately by

the

the reſiſtance which the thread *b* of the ſcrew oppoſes to the tooth of the wheel, keeping the direction *b g* perpendicular to the radius C *b*. This thread *b* therefore acts by the radius of the wheel C *b*, whilſt the weight P acts by the radius of the roller or windlaſs C *d*; ſo that to maintain an equilibrium, the force at *b* ſhould be to the weight P as C *d*, as the radius of the roller is to the radius of the wheel C *b*. Thus the relation which the weight P ſhould have to the power Q in caſe of an equilibrium, may be expreſſed in this manner. The weight is to the power as the product of the radius of the wheel, multiplied by the circumference which the radius of the handle deſcribes, is to the product of the radius of the windlaſs, multiplied by the height of the pace of the ſcrew.

The motion of the wheel being exceedingly ſlow in proportion to that of the handle, it follows that a very ſmall power is capable of raiſing a conſiderable weight by means of the perpetual ſcrew. For example, ſuppoſe, as in fig. 8. a wheel C *b*, which has nine teeth, and a ſcrew which has but one thread, and which, at each round, cauſes only one tooth of the wheel to paſs; ſuppoſe the circumference of the windlaſs T to be one foot, and the circumference which the radius of the handle E M deſcribes to be five feet; when the wheel C *b* ſhall have performed an entire round, the weight P will be raiſed one foot, and the ſpace run through by the power Q will be 19 times five feet or 95 feet. The velocity of the power Q will then be to the velocity of the weight P as 95 is to one; conſequently this power, with the effort of 1 lb. is capable of raiſing 95 lb.; and if its effort was equal to 30 lb. it would raiſe 2,850 lbs.

If the wheel C *b* had as many more teeth as it has, or if the radius E M of the handle were as long again, the

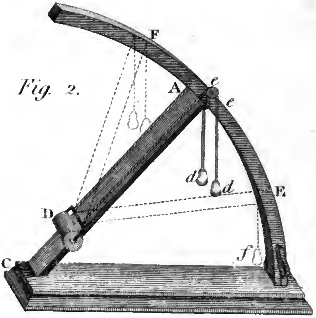
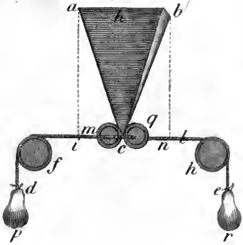


Fig. 2.

Fig. 3.



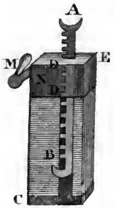
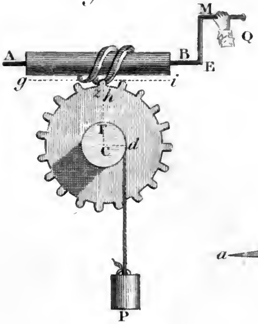


Fig. 1

Fig. 4.

Fig. 6.



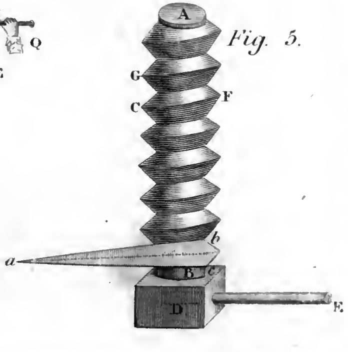


Fig. 5.

the ſame power Q would produce a double effect, that is, it would raiſe 5,700 lbs.

But if, without changing the number of teeth in the wheel C *b*, or the length of the radius E M of the handle, another perpetual ſcrew is placed upon the axis of the wheel inſtead of the windlaſs T, the thread of which ſhould catch with the teeth of a ſecond wheel of the ſame number of teeth with the firſt, and to which ſhould be annexed the windlaſs T, which is to ſuſtain the weight P, then the ſame power Q would be capable of raiſing a weight 19 times as great; in other words, this power, intrinſically only 30 lbs. would be able to raiſe the weight of 54,150 lbs.

Such are the ſimple machines which have been generally conſidered as the baſes of all others.

If all the materials of which machines are compoſed were perfectly hard, perfectly poliſhed, and if the ropes which are often uſed to tranſmit the motive force from one part of the machine to another had a perfect flexibility, the theory of equilibrity, of which we have hitherto ſpoken, would be ſufficient to determine, in every caſe, the force requiſite to counterbalance a given reſiſtance; and this force once found, it would be clear, that by augmenting it ever ſo little, the equilibrium would be deſtroyed and the reſiſtance overcome; but the friction of ſurfaces one againſt another, and the reſiſtance which cords produce by being wrapped round pullies and cylinders, neceſſarily impede the motion of machines; and it is extremely difficult to eſtimate, with even tolerable exactneſs, the amount of the reſiſtance which may in different circumſtances proceed from theſe cauſes.

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 formidable is the power of fire, that by one of the moſt conſiderable 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 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 ſyſtem of Epicurus; and

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

† Lucret. Lib. I. 636.

indeed

indeed the Epicureans, as well as the Peripatetics, ſeem to have conſidered fire as a diſtinct elementary ſubſtance, capable of combining with the other elements, but by no means the matter from which they are originally generated.

The hiſtory of error can afford but little inſtruction, otherwiſe volumes might be filled with the fantaſtical opinions which have been from time to time entertained concerning the element of fire. On the revival of letters and philoſophy, our illuſtrious Bacon, in a treatiſe expreſsly written upon the ſubject [*], endeavours to prove, that heat is no other than an inteſtine motion or vibration in the parts of bodies; and he was followed by moſt of the philoſophers of this kingdom during the laſt century. The opinion of Bacon is ſupported by a variety of facts, which are adduced by Mr. Boyle in a diſſertation on the *mechanical origin* of *heat and cold* [†]; nor does the ſyſtem appear repugnant to the ſentiments of Newton; though he ſpeaks of it with that diffidence which is always obſervable in his writings, 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,

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[*] De Forma Calidi.

[†] Mr, Boyle, however, though thus apparently deceived with reſpect to the cauſe of heat, in another eſſay reaſons juſtly with reſpect to its effects. He conſiders ice not as the preternatural ſtate of water, but water as ice preternaturally thawed by heat.

Boyle on the nat. and preternat. State of Bodies.

[‡] Optics, 318. 349.

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 increaſe 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 preſſure of the external air; tubes hermetically ſealed were therefore preſently ſubſtituted, and the coloured liquors themſelves were found to be ſufficiently expanſible to mark

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

† Mem. de l'Acad. Roy. 1709.

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 elementary 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 vibration of the particles, 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 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 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 or heat 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 was not great, it followed that a conſiderable quantity of the matter of heat or fire is neceſſary to keep water in a ſtate of vapour. When any quantity of heat is expelled from a body, in ſuch a manner as to affect our touch, it is termed, according to Dr. Black's theory, *ſenſible* heat; and when it is abſorbed by any body, and exiſts in combination with that body, either in a fluid or vapourific ſtate, it is termed *latent* heat. It is alſo evident from what has been ſtated, that the opinion of theſe later philoſophers is, that heat or fire, which has alſo been called *igneous fluid*, *matter of heat*, and lately by the French chemiſts *caloric*, is a diſtinct ſubſtance or fluid, which has an attraction for all other ſubſtances; that it pervades moſt bodies; that it is the only permanent fluid in nature, and the cauſe of fluidity in all other bodies. That not only common fluids, ſuch as water, but all elaſtic fluids, ſuch as vapour and air, owe their exiſtence in that ſtate to the preſence of heat; and that it is ſubject to all the laws of attraction, and is more forcibly attracted by ſome bodies than by others.

The ſchool of Dr. Black ſeems to have conſidered light and heat as eſſentially different; and Dr. Scheele, a Swediſh philoſopher, has endeavoured to prove, that light is formed by an union of the matter of heat with phlogiſton 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 ſyſtem concerning

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

cerning the generation of heat within animal bodies, which he conſiders as derived from the air we breathe. The air being condenſed on the lungs, the heat which it contained in a latent ſtate is abſorbed and diſperſed over the animal body.—But this is a ſubject which properly belongs to another part of the work.

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nection with the ſubject. No man was ever better calculated for promoting uſeful ſcience than Dr. Crawford. In him induſtry and perſeverance were eſtabliſhed habits; and candour and caution characteriſtic diſpoſitions. With all the advantages of a liberal education, he united great natural ſagacity, acuteneſs, and ingenuity; yet the laſt quality was tempered by a coolneſs and collectedneſs of mind, which effectually prevented his too haſtily acceding to the raſh concluſions of plauſible theory. With all his excellence as a ſcientific man, he poſſeſſed the gentleſt of tempers, the moſt friendly heart.—From his promiſed reviſion of this work, I had flattered myſelf with great advantages; but what are private loſſes compared with that of the public! If, after having ſerved his country in a public capacity, the family of ſuch a man ſhould be left in indigence, to what a ſtate is the national ſpirit reduced!

CHAP. II.

OF FIRE (CALORIC) AND ITS PROPERTIES.

Inquiry whether Heat or Fire is a Subſtance or Quality.—Fire a Subſtance.—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, 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

nies 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

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, by a late ingenious philoſopher *. He conſtructed an inſtrument, in the form of a ſmall vane or weathercock. 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

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

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 ſubſtance. 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 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.

7thly. That heat is generally accompanied by motion, is no proof that heat and motion are the ſame;

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* Jones's Phyſiol. Diſq. p. 85.

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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 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 ſtate, which indeed occaſionally cauſes their expanſion or dilatation; it is then the more probable ſuppoſition, that the fire or caloric 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 amongſt 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 caloric or the matter of fire, which expands the bodies into which it enters, and conſequently rather diminiſhes their ſpecific gravities.

8thly. All the other phenomena of nature are more

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* 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.

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.

Heat and light are the only means by which we are enabled to diſcover the preſence of fire, I conclude, therefore, that they are both effects of the ſame cauſe. The rays of the ſun, when concentrated to a certain degree, produce intenſe heat; and heat, when violently excited by attrition, &c. if the body in which it is excited is in favourable circumſtances, will generally terminate in flame, and conſequently in the emiſſion of light. This hypotheſis receives a ſtrong confirmation from an experiment of Mr. Boyle. He coloured the ſurface of a large tile, one half white, and the other black: after ſuffering it to lie for ſome time, expoſed to the ſummer ſun, he found that while the whited part of the ſurface, or that part which reflected back the rays of light, remained quite cool, the black part, which imbibed them, was grown extremely hot. He occaſionally left a part of the tile of its native red; and, after expoſing the whole to the ſun, found that this part grew hotter than the white, but not quite ſo hot as the black part. He obſerves, that rooms hung with black are not only the darkeſt but the warmeſt alſo; and a virtuoſo of unſuſpected credit aſſured him, that in hot climates he had ſeen eggs well roaſted in a ſhort time, by only blacking the ſhells, and expoſing them to the ſun. This fact was afterwards completely eſtabliſhed by Dr. Franklin, who expoſed ſeveral pieces of cloth of different colours upon the ſurface of ſnow; he found that the black ſunk conſiderably beneath the ſurface, conſequently that it imbibed a large quantity of heat, whereas the white, which reflected the greater part of the

the rays of light, had imbibed ſcarcely any heat whatever.

The only objection of any moment which has ariſen againſt this doctrine is, that there exiſt certain bodies, ſuch as what are called the ſolar phoſphori, putreſcent ſubſtances, and rotten wood, which emit or reflect light, without apparently poſſeſſing the ſmalleſt quantity of ſenſible heat. If however we conſider the extreme weakneſs of the light which is emitted by theſe ſubſtances, the objection will appear to have little force. The moſt concentrated moon-light, in the focus of a concave mirror, is not more than the three hundredth part of the intenſity of common ſunſhine *; and yet the light from theſe ſubſtances is not to be compared with that of the moon. Nay, the analogy between heat and light receives confirmation from theſe very ſubſtances; for the property which they poſſeſs of emitting light, is greatly increaſed by an acceſſion of heat; and even phoſphori, in which the light has for ſome ſpace of time been dormant, or in which it is apparently exhauſted, will emit light upon the application of heat alone †.

I conceive fire therefore, or caloric, as termed by the French chemiſts, to be the elementary principle or cauſe of heat and light. Caloric in a diſengaged ſtate, or in the act of paſſing from one body to another, impreſſes our organs with the ſenſe of heat; and in a rarefied and projectile ſtate, it 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

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

† Prieſtley's Optics, part iv. ſ. 1.

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 caloric or the matter of 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 latent or combined ſtate, as the efficient cauſe of fluidity both in the incompreſſible and elaſtic or aërial fluids. I ſhall firſt enter into a brief detail of the principal and known properties of caloric; 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 caloric: 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 con-

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* See Jones's Phyſ. Diſq. p. 38.

tact 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 a perfect equilibrium is produced, 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 ſame length will be conſumed to aſhes at the end which is in the fire before the other end is ſufficiently heated to burn the hand. A ball of lead and a ball of wool may be of exactly the ſame temperature by the thermometer, but they will not appear of the ſame 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, becauſe 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 thoſe bodies through which the element of fire moſt rapidly circulates, are called good conductors.

The power of conducting the matter of fire ſeems to depend upon the texture of bodies, that is, upon the contact of their parts *; hence the exceſſive ſlowneſs with which heat is communicated to bodies of a rare and ſpongy texture. Thus flannel, wool, and feathers, are conſidered as warm coverings, not becauſe they poſſeſs more heat in themſelves (for they ſerve to preſerve any cold body in a cool ſtate better than other ſubſtances) but becauſe they prevent the eſcape of the animal heat from our bodies. It is a well-known fact, that ice is generally kept in ice-houſes in ſtraw or wool, thoſe ſubſtances, from the rarity of their parts, preventing the entrance of the matter of 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,

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* This is proved by an eaſy experiment:—If a cube and a ſphere of the ſame metal are put upon a plane intenſely heated, the heat will flow faſter into the cube; and if the ſame bodies are previouſly heated, and expoſed on a cold plane, the cube will cool ſooneſt.

† 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.

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.

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^{s} 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 caloric 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

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[*] 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.

to a hand which is of a lower temperature *. Travellers, therefore, from a warm to a cold country, will have ſenſations very different from thoſe who travel in an oppoſite direction, ſhould 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 leſs heat than uſual, will have the ſenſation of warmth; and the others, on the contrary, will experience a degree of cold ſufficient to excite conſiderable uneaſineſs.

3dly. The matter of fire will exiſt in a ſtate of combination. I do not contend for the term chemical combination, in the ſtrict and literal ſenſe of the word; it is ſufficient if it can be proved, that caloric may exiſt in bodies in a *latent* ſtate, or in a ſtate not perceptible to our ſenſes. It will be found by obſervation, that every body which exiſts contains a quantity of the matter of fire in this fixed or neutralized ſtate, diſarmed of all its active, penetrating, and deſtructive qualities, like an acid and an alkali in combination. If the coldeſt bodies with which we are acquainted are condenſed or brought into a ſmaller compaſs, a quantity of caloric will be emitted. If a piece of lead or iron is beaten with a hammer, or compreſſed in a vice, ſo as to force it to contract its dimenſions, it has been already remarked that a degree of ſenſible heat will be produced.

Fluids, from their very nature and conſtitution, contain a greater quantity of caloric in a latent ſtate than ſolid bodies: indeed it is now univerſally admitted, and may be eaſily 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 elaſti-

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

city 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 caloric than in its natural ſtate; on the ſlacking of lime therefore a very intenſe heat is produced, the matter of 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 caloric 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 caloric 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

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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 ſpirit 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 Muſchenbroek was aſtoniſhed at the freezing of a wet cloth which was hung up to dry, when there was no appearance of froſt in the atmoſphere: the ſolution of the difficulty is, the temperature of the air at the time muſt have been within ſome degrees of froſt, and the temperature of the cloth was ſuddenly reduced to the freezing point by the loſs of a part of its heat from evaporation.

Let it be remembered, that in all theſe inſtances there is an evident acceſſion or increaſe of the matter of fire thrown into the bodies which are rendered fluid,

fluid, and yet the temperature or obvious heat of the fluids is not increaſed, as may be proved by the thermometer; wherefore it is plain that the caloric exiſts in theſe ſubſtances in a *latent* or combined ſtate.

4thly. The matter of fire is elaſtic, as is proved evidently from all its effects. There is indeed reaſon to believe that caloric is the only fluid in nature which is permanently elaſtic, and that it is the cauſe of the elaſticity of all fluids which are eſteemed ſo.

From the elaſticity of this element it reſults that all natural bodies can only retain a certain quantity of it, without undergoing an alteration in their ſtate and form. Thus a moderate quantity of fire admitted into a ſolid body expands it; a ſtill larger quantity renders it fluid; and if the quantity is ſtill increaſed, it will be converted into vapour. But this, and all the other properties of caloric, will be better 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 1,800 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.

CALORIC, 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 $\frac{1}{60}$th longer than before; and a glaſs cylinder, a fathom long, under the ſame circumſtances, gained $\frac{1}{50}$th in length. A metalline ring thus heated was increaſed $\frac{9}{100}$ in its diameter: and a glaſs globe became extended $\frac{1}{100}$ part by the heat of the hand only applied to its ſurface *.

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

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

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 great 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 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 of 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 quan-

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* Jones's Phyſ. Diſq. p. 99. 100.

† Ib. p. 98.

‡ Ib. p. 98.

tity 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 proportion 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 ſpirit 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 thermometer ariſes from the viſcidity of the oil, which occaſions it to adhere to the ſides of the veſſel, ſo that a conſiderable quantity of the fluid being retained by the glaſs, when the thermometer ſinks, it appears to ſink lower at firſt than it ought to do, according to the natural temperature.

Theſe thermometers, therefore, were all of them ſuperſeded by the famous invention of Olaus Roemur, improved by Fahrenheit, who ſubſtituted mercury inſtead of the other fluids. Mercury is found to be a more homogeneous body than any other fluid, and more regular in its expanſions, beſides that it is capable of exhibiting a more copious ſcale of both heat and cold.

Sir Iſaac Newton, obſerving that water uniformly froze with a certain degree of cold, and as uniformly boiled when the heat was increaſed to a certain degree, took what is called the freezing point for the commencement of his ſcale, and from that to the boiling point he counted thirty four degrees, and divided his ſcale 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 ſcale alſo at the freezing point, yet admits of ſeveral degrees below it, and proceeds both ways from 0; the boiling point in his ſcale is at 80° above 0. The ſcale of Fahrenheit begins conſiderably below the freezing point, at that period of cold which is produced by ſurrounding the bulb of the thermometer with a mixture of ſnow or pounded ice and ſal ammoniac or ſea-ſalt: he divided his ſcale into minuter portions than either Newton or Reaumur, on which account it is well known that the boiling point in Fahrenheit'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 Fahrenheit; and that the freezing point, which is the commencement of both the other ſcales, is in Fahrenheit's at 32° above 0.

The graduating a mercurial, or Fahrenheit'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

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* From Torricelli, the inventor.

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ſome other ſtopper, to prevent the air from ruſhing in. When by theſe 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 the mean heat of the two component parts †. This fact was

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* 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.

† 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. 2d edit.*

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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 Fahrenheit; 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 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 dimen-

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* Crawford on Heat, p. 47, 48.

ſions 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 earthenware commences at a low red heat, and proceeds regularly till the clay becomes vitrified. Mr. Wedgwood's thermometer, therefore, 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 caloric, 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 caloric 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

which they are produced kept floating in a quantity of fire. To underſtand how caloric 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 (aquafortis 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 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

ſolid ſtate a quantity of caloric 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 caloric 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 al-

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

ways 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; 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 excite that degree

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of heat) are abſorbed, or reduced to a ſtate of combination, ſo as not to produce any effect on the thermometer *.

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 caloric 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 caloric 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 Fahrenheit, 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. 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

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* Crawford on Animal Heat, p. 72.

† Ibid.

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. 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 Fahrenheit's ſcale at 212°.

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

ſtantly 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 caloric 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 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.

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 caloric 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

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

† I have been told to 412.

‡ Crawford on Animal Heat, p. 77.

‖ Ibid. p. 78.

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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 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

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* 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

his Phyſiological Diſquiſitions, ſerves well to mark its effects. ‘ A workman, who with ſome others was employed to repair a ſteam-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 caloric 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 returned, and the preſſure

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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 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.

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 he 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 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

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

cork

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 its temperature ſunk ſurprizingly. When the ether was firſt put in, its temperature was about 58°, but it became ſo cold when boiling, that a quantity of water in a veſſel contiguous to it was ſuddenly frozen. The manner in which theſe phenomena may be explained is this:—The weight of the atmoſphere being removed, the heat which the ether contained was ſufficient to make it boil. The elementary fire which the ether loſt in boiling was diſpoſed of in forming a vapour more ſubtile than the ether itſelf; which could not, conſiſtently with the principles eſtabliſhed, be formed without the abſorption of a conſiderable quantity of the matter of fire. Now as it appears that water and ſpirit of wine boil in vacuo

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* Chem. Eſſays, vol. iii. p. 162.

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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, ſhould boil in vacuo at 24° below 0, a degree of cold ſufficient to freeze any water that might happen to be in contact with the veſſel which contains the ether.

As the weight of the atmoſphere varies ſome degrees at different times, it is evident, from theſe remarks, that the boiling point of fluids will alſo occaſionally vary. Boerhaave ſuppoſes, that, according to the changes of the atmoſphere, as marked by the barometer, the heat of boiling water may vary occaſionally eight or nine degrees *; 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° †.

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* Boerhaave Chem. quoted by Watſon, Chem. Eſſ. vol. iii. p. 157.

† 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.

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 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 ebullition 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 caloric, 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 reaſon why water, either hot or cold, immediately extinguiſhes flame, will eaſily be underſtood from what has been premiſed. When a quantity of water is thrown upon an ignited body, it is immediately converted into vapour, and this proceſs ſuddenly deprives the burning body of as much elementary fire as the vapour is naturally diſpoſed to abſorb. If therefore the water is applied in ſufficient quantity, the whole of the caloric will be imbibed by the evaporation, and the body will be left totally deſtitute of heat. For the ſame reaſon it is evident, that water will prevent the melting of metals, or of any ſubſtances which require a degree of heat ſuperior to the boiling point, to render them fluid: for the water, being in contact with the other ſubſtance, will not permit its temperature to increaſe, and all the ſuperfluous fire which would heat it above the boiling point, if the water was not there, is carried off by the evaporation of that fluid *.

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* 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 veſſel, the bottom is cool; but the moment it ceaſes to boil, the bottom becomes hotter." The whole of the paradox appears to be founded on an error of the ſenſe. When a perſon applies his finger to the veſſel, though he applies it for a conſiderable time, it is not heated more than he can endure, for the blood in the courſe of its circulation loſes ſome of its heat before it arrives at the extremities; and till the blood in the extremities is heated to the ſame degree with that of the heart we feel no pain from burning; but as ſoon as this is effected, the leaſt degree of heat becomes painful. When the finger is firſt applied to the bottom of the veſſel after it is taken 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.

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 matters 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 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:

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 caloric; 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

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* 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.

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 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 Landaff. 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 increaſe of weight from various experiments, between twelve and three o'clock, was ſix grains in one quarter of an hour from twenty ſquare inches of earth. At this rate of evaporation, it is eaſy to ſee that, computing at ſeven thouſand grains troy to one pint of water, and eight pints to a gallon, not leſs than one thouſand ſix hundred gallons of water would be raiſed from one acre of ground in twenty-four hours. It may well be ſuppoſed that the quantity will be ſtill greater when the ground has been drenched with rain. In order to prove this, the ſame judicious philoſopher made two other experiments, one of them the day after the ground had been wetted by a thunder-ſhower; and to aſcertain the circumſtances more exactly, he took the heat of the earth by a thermometer laid on the graſs, which in the firſt experiment was 96°, when the evaporation was at the rate of one thouſand nine hundred and ſeventy-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 thouſand eight hundred gallons from an acre in twelve hours; the earth was hotter than the air, being expoſed to the reflexion of the ſun's rays from a brick wall *.

It is the vapour which is exhaled in this manner from the earth, which forms thoſe miſts ſo commonly

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* Watſon's Chem. Eſſays, vol. iii. Eſſ. 2.

obſerved in marſhy grounds. If a hole is 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.

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

* 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.

conſideration

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 caloric 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 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

bly 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 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.

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

"Like words congeal'd in northern air."

HUDIBRAS.

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 which it is moſt eaſily detached, is *air*. If therefore any ſubſtance can be found in nature which has a greater attraction for the baſis 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,

tion, 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 caloric 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 place. The pure and inflammable airs unite together, or are condenſed 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 proceſs of burning, when a quantity of inflammable or combuſtible ſubſtances are heaped together, and fire introduced among them, by the action of the fire the inflammable part is firſt expanded from its ſolid ſtate into a ſtate of inflammable vapour, it comes neceſſarily into contact with the pure air of the atmoſphere, and the action of the fire ſtill conti-

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nuing, the matter of fire is detached from the air, and combuſtion enſues in the ſame manner as in the former caſe, when the pure and inflammable airs are fired by the electric ſpark.

Hence there can be no combuſtion without a ſupply of pure air; and from this conſideration moſt of the phenomena of combuſtion may be explained. In a common coal fire, if the coals cake or adhere in ſuch a manner that the inflammable part cannot come in contact with the external air, the fire is neceſſarily extinguiſhed. 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 conſumed, takes the form of ſmoke and ſoot, and adheres to the ſide or top of the place or veſſel which contains the fire. The flame of a common lamp or candle may be conſidered 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 ſoot, 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

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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 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 with a very ſmall ſupply of air, as when included within the barrel of a gun, and cloſely wadded. 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 metallic ſubſtances, yet the element of fire, or caloric, will penetrate them, 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 caloric) cannot be excluded. When therefore the matter or elementary part of 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 nearly excluded *.

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* Gunpowder is a mixture, which in an hundred parts contains about 75 of nitre, 9½ of ſulphur, and 15½ of charcoal. The effects of gunpowder depend on the ſudden production of a quantity of air,

According to the different properties of bodies, they are more or leſs diſpoſed to ignition. Iron is ignited with great difficulty; on the contrary, not only

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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 flowers of ſulphur, till the whole is very accurately mixed. If a drachm of this powpowder 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 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 is 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

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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.

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.

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.

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 ſeparation 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 into a paſte, the air is rapidly attracted, and the maſs becomes ſo hot as to take 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 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. 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 aid of this ſimple contrivance, M. Lavoiſier has been able to aſcertain, with apparent accuracy, the quantity of caloric diſengaged in moſt of the common proceſſes of combuſtion *.

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* '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 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 *.

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* 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.

In

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.
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 lbs. 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 lb. 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 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 trouble-

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

ſome 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 1⅓ gr. of charcoal have ſuffered combuſtion, along with 37.38.34 grs. or 6 oz. 3 gros, 66.34 grs. of ozygen. 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 allowed to burn ſlowly in an ice apparatus, melted 133 lbs. 2 oz. 5⅓ gros of ice. According to my experi-

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ments 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.’ *Lavoiſier's Chemiſtry.*

A SCALE OF HEAT.

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

	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

	Fahr.
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
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 feveriſh 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 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 reflexion is equal to the angle of incidence.

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* The unſcientific reader is earneſtly requeſted to give particular attention to the following ſhort axioms and definitions, which will enable him not only better to underſtand this chapter, but all the ſucceeding; and if in the courſe of this book any diffi-

culty

To this may be added the opinion of Ariſtotle, who ſuppoſed that rainbows, halos, and mock ſuns, were occaſioned

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culty ſhould occur, he will probably find it removed by referring to this note.

1. Light is a matter, the particles of which are extremely ſmall, which, by ſtriking on our viſual organs, gives us the ſenſation of ſeeing.

2. The particles of light are *emitted* from what are called *luminous* bodies, ſuch as the ſun, a fire, a torch, or candle, &c. &c.; it is *reflected* or ſent back by what are termed *opake* bodies, or thoſe which have no power of affording light in themſelves.

3. Light, whether emitted or reflected, always moves in *ſtrait* or *direct lines*, as may eaſily be proved by looking into a bent tube which evidently obſtructs the progreſs of the light in direct lines.

4. By a *ray* of light is uſually meant the leaſt particle of light that can be either intercepted or ſeparated from the reſt. A *beam* of light is generally uſed to expreſs ſomething of an aggregate or maſs of light greater than a ſingle ray.

5. *Parallel rays* are ſuch as proceed equally diſtant from each other through their whole courſe. The diſtance of the ſun from the earth is ſo immenſe, that rays proceeding from the body of that luminary are generally regarded as parallel.

6. *Converging rays* are ſuch as, proceeding from any body, approach nearer and nearer to each other, and tend to unite in a point. The form of rays thus tending to a union in a ſingle point has been compared to that of a candle extinguiſher; it is in fact a perfect cone.

7. *Diverging rays* are thoſe which, proceeding from a point, continue to recede from each other, and exhibit the form of an inverted cone.

8. A ſmall object, or a ſmall ſingle point of an object, from which rays of light diverge or indeed proceed in any direction, is ſometimes called the *radiant*, or *radiant point*.

9. Any parcel of rays, diverging from a point, conſidered as ſeparate from the reſt, is called a *pencil of rays*.

10. The *focus of rays* is that point to which converging rays tend, and in which they unite and interſect or croſs each other. It may be conſidered as the apex or point of the cone; and it is called the focus (or fire place) becauſe it is the point at which burning-glaſſes burn moſt intenſely.

11. The *virtual* or *imaginary* focus is that ſuppoſed point behind a mirror or looking-glaſs, where the rays would have naturally united, had they not been intercepted by the mirror.

occaſioned by the reflexion of the ſun's beams in different circumſtances. We have reaſon to believe, that the uſe

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12. *Plane mirrors* or *ſpeculums* are thoſe reflecting bodies, the ſurfaces of which are perfectly plain or even, ſuch as our common looking-glaſſes. *Convex* and *concave mirrors* are thoſe the ſurfaces of which are curved.

13. An *incident ray* is that which comes from any body to the reflecting ſurface; the *reflected ray* is that which is ſent back or reflected.

14. The *angle* of *incidence* is the angle which is formed by the line which the incident ray deſcribes in its progreſs, and a line drawn perpendicularly to the reflecting ſurface; and the *angle* of *reflection* is the angle formed by the ſame perpendicular and the reflected ray, thus,  *c*; where *a* is the angle of incidence, *b* the angle of reflection, and *c* the reflecting ſurface.

15. By a *medium* opticians mean any thing which is tranſparent, ſuch as void ſpace, air, water, or glaſs, through which conſequently the rays of light can paſs in ſtrait lines.

16. The *refraction* of the rays of light is their being bent, or attracted out of their courſe in paſſing obliquely from one medium to another of a different denſity, and which cauſes objects to appear broken or diſtorted when part of them is ſeen in a different medium. It is from this property of light, that a ſtick or an oar which is partly immerſed in water appears broken.

17. A *lens* is a tranſparent body of a different denſity from the ſurrounding medium, commonly of glaſs, and uſed by opticians to collect or diſperſe the rays of light. They are ingeneral either *convex*; that is, thicker in the middle than at the edges, which collect and by the force of refraction converge the rays, and conſequently magnify; or *concave*, that is, thinner in the middle than at the edges, which by the refraction diſperſe the rays of light, and diminiſh the objects that are ſeen through them.

18. *Viſion* is performed by a contrivance of this kind. The cryſtalline humour, which is ſeated in the fore part of the human eye, immediately behind the pupil, is a perfect convex lens. As therefore every object is rendered viſible by beams or pencils of light which proceed or diverge from every radiant point of the object, the cryſtalline lens collects all theſe divergent rays, and cauſes them to converge on the back part of the eye, where the retina or optic nerve is ſpread out; and the points where each pencil of rays is made to converge on the retina,

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

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tina, are exactly correſpondent to the points of the object from which they proceed. As however, from the great degree of convergence which this contrivance will produce, the pencils of light proceeding from the extreme points of the object will be made to croſs each other before they reach the retina, the image on the retina is always inverted. (See Plate XX. fig. 39.)

19. The magnitude of the image painted on the retina will, therefore, it is evident, depend on the greatneſs or obtuſeneſs of the angle under which the rays proceeding from the extreme points of the object enter the eye. For it is plain, that the more open or obtuſe the angle is, the greater is the tendency of theſe rays to meet in a point and croſs each other: and the ſooner they croſs each other, after paſſing the cryſtalline lens, the larger will be the inverted image painted on the retina. (See Plate XX. fig. 40.) The *viſual angle*, therefore, is that which is made by two right lines drawn from the extreme points of any object to the eye; and on the meaſure of that angle, the apparent magnitude of every viſible object will depend.

20. The *priſm* uſed by opticians is a triangular piece of fine glaſs, which has the power of ſeparating the rays of light.

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 are 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 diſk, 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

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* The face of the ſun.

Porta,

Porta, of Naples, invented the camera obſcura; and his experiments upon that inſtrument convinced him that light is a ſubſtance, by the intromiſſion of which into the eye viſion is performed; for it is proper to mention, that before his time the opinion was almoſt 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

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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 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

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* An account which is very commonly received is, that ſome of his children playing in his ſhop with ſpectacle glaſſes, perceived that when they held two of theſe glaſſes between their fingers, at a certain diſtance from each other, the dial of the clock appeared greatly magnified, but in an inverted poſition. From this their father took the idea of adjuſting two of theſe glaſſes on a board, ſo as to move them at pleaſure.

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 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 exhibiting the light, tranſmitted through it, coloured.

In 1625, the curious diſcovery of Scheiner was publiſhed 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 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 Caſini and Roemer, by obſerving the eclipſes of Jupiter's piter'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 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.

lours. 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 reduced to a circular form, as regularly as if it had paſſed through neither of them. After many conjectures and experiments relative 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 or particles of light of one colour were found to be 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, according to which they were tranſmitted through the priſm to the oppoſite wall. It was further evident from theſe experiments, that as the rays of light differ in refrangibility, ſo they alſo differ in exhibiting particular colours, ſome rays producing the colour red, others that of yellow, blue, &c. and of theſe different-coloured rays, ſeparated by means of the priſm according to their different degrees of refrangibility, the oblong figure on the wall was compoſed. But to relate the great variety of experiments, by which he demonſtrated theſe principles, or the extenſive application of them, would lead me too much into detail; let it ſuffice to ſay, that he applied his principles to the ſatisfactory explanation of the colours of natural bodies, of the rainbow, and of moſt of the phenomena of nature, where light and colour are concerned; and that almoſt every thing which we at preſent know upon theſe ſubjects was laid open by his experiments.

His obſervations on the different refractive powers of different ſubſtances are curious and profound; but chemiſtry was at that period ſcarcely in a ſtate ſufficiently advanced to warrant all his concluſions. The general reſult is, that all bodies ſeem to have their refractive powers proportional to their denſities, excepting ſo far as they partake more or leſs of inflammable or oily particles.

The diſcovery of the different refrangibility of the component rays of light ſuggeſted defects in the conſtruction of teleſcopes, which were before unthought of, and in the creative hand of a Newton led to ſome no leſs extraordinary improvements in 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

quently 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 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 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

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

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 diſperſión 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; 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

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 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, 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.

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 light as analogous to ſound, which is known to depend entirely on the pulſations of the air upon the auditory nerves; and in ſupport of this opinion, it has been even lately urged *, 1ſt. That

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

ſome diamonds, on being rubbed or chafed, are luminous in the dark. 2. That an electric ſpark, 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 eſcape, in ſuch a caſe, to diſtant places, but the whole proceeds in the direction to which it is deſtined by the hand of the operator. Weaker or ſtronger ſparks of this fluid are alſo known to differ in colour; the ſtrongeſt are white and the weakeſt red, &c.

To this opinion, however, there are many preſſing and, indeed, inſurmountable objections. 1ſt, The velocity of ſound bears a very ſmall proportion to that of light. Light travels, in the ſpace of eight minutes, a diſtance in which ſound could not be communicated in ſeventeen years; and even our ſenſes may convince us, if we attend to the exploſion of gunpowder, &c. of the almoſt infinite velocity of the one compared with that of the other. 2dly, If light depended altogether on the vibrations of a fluid, no ſolid reaſon can be aſſigned why this fluid ſhould ceaſe to vibrate in the night, ſince the ſun muſt always affect ſome part of the circumambient fluid, and produce a perpetual day. 3dly, The 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 vibrat-

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ing 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 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

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* "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.

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 when concentrated by a burning glaſs, 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 ſtate. Fire, according to theſe philoſophers, is produced by the accumulation or concentration of the particles; light is the effect of the rapid projectile motion of the ſame particles. Fire or heat may therefore exiſt to a conſiderable degree, as it is found to do occaſionally in metallic bars, without being ſufficiently diſengaged to aſſume the projectile ſtate, and to be forcibly emitted or projected from the burning body. The ſame matter may alſo exiſt in its active and projectile ſtate, or, in other words, in the form of light, but too much diffuſed to produce the ſenſation of burning, or to effect the diſſolution of any body, or the ſeparation of its parts by combuſtion. To the great elaſticity of the matter of fire, ſo obvious in all the phenomena of fluidity, both theſe effects are aſcribed. When a quantity of this matter is introduced into any ſolid body, the repulſion which exiſts between its particles will occaſion the diſſolution of that body; and when it becomes perfectly free and diſengaged, the ſame repulſion will cauſe a quantity of its

its particles to be emitted with a rapid projectile force, and will produce the effects of light *. The light of the ſun is conſidered as " the ſame matter propelled by the ſame powers, in 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. The abſorption of

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* 'When we conſider that the elaſticity of aeriform fluids is owing to the matter of fire; that a cannon ball is propelled 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.

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 of the fluid. 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 ſpirit of wine, or through any other tranſparent inflammable ſubſtance, the latter will not be ſet on fire; but if there is any opake body (as a ſpoon or other veſſel) placed under the ſpirit or the tranſparent body, which by intercepting may ſerve to accumulate the particles of light, the ſpirit or inflammable matter will be immediately inflamed. Conformably to theſe

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* See p. 76.

† That of 1,000 miles.

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 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

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* Nicholſon's Phil. vol. i. p. 258. † Ibid, p. 257.

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 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

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

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 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

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* A cannon ball flies with the 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.*

† Nicholſon's Phil. vol. i. p. 257.

‡ Enfield's Phil. 131.

§ Nicholſon's Phil. vol. i. p. 258.

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 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

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[*] Prieſtley's Optics, p. 385.

[†] See p. 95.

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one twelve hundred millioneth 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 $\frac{1}{40000}$ 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 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

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* Prieſtley's Optics, p. 389.

projected, they are found, by a variety of experiments, to be ſubject to the ſame laws of ATTRACTION 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 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

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

‡ Prieſtley's Optics, p. 367.

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 the moſt extraordinary phenomena of light, refraction and inflexion. That incomparable philoſopher has alſo ſhewn that light is not only ſubject to the law of attraction, but of repulſion alſo, ſince it is repelled or reflected from certain bodies; a property which was long known, but was never underſtood till he gave us a ſyſtem, which accounts for the general operations of nature, upon fewer and ſimpler principles, yet in a manner much more ſatisfactory than any which had preceded. But to enumerate and briefly explain theſe general properties would extend this chapter to an improper length, and would probably in ſome meaſure tend to confuſe the ſtudent.

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* Prieſtley's Optics, p. 368, 369, 370.

CHAP. III.

GENERAL VIEW OF THE PHENOMENA OF REFLEXION.

Opake Bodies do not reflect the Whole of the Light that falls on them.—Law of Reflexion.—Reflexion from plane Surfaces.—Reflexion from convex Surfaces.—From concave Surfaces.—Phenomena of Reflexion from plane Mirrors explained.—From convex Mirrors.—From concave Mirrors.—Prominent Image from a concave Mirror.—The cylindrical Mirror.—The Rectification of diſtorted Figures by this Mirror.—The conical Mirror.

IT has been already intimated that the rays of light, which proceed from any luminous body, move always in ſtrait lines, unleſs this direction or motion is changed by certain circumſtances, and theſe are reflection, refraction, and inflexion. Of the firſt of theſe it will be proper to treat in this chapter, becauſe by purſuing the ſubject in this order, it will I conceive be more eaſily comprehended by the unſcientific reader.

A common paſtime of children with a piece of glaſs oppoſed to the ſun, and caſting by means of it a vivid ſpot of light in various places at will, proves that the rays of light may be reflected by certain bodies; and more accurate obſervation will convince us, that every body that is not luminous in itſelf is made viſible to our ſenſe by reflected light.

We are not to ſuppoſe, however, that every opake body reflects the whole of the light which falls upon it. On the contrary, it is only a limited portion which is regularly reflected according to the known law of reflexion; another portion may be conſidered as abſorbed by the body, or as rendered latent by ſome cauſe

cauſe which we cannot at preſent explain, and the quantity which is thus loſt or abſorbed differs according to the nature and circumſtances of the reflecting ſurface.

The great law of reflexion, and which ſerves to explain all its phenomena, is this, *that the angle of reflexion is always equal to the angle of incidence.* It was already intimated, that by the angle of incidence is meant the angle made by a ray of light with a perpendicular to the reflecting ſurface at the point where the ray falls; and by the angle of reflexion, the angle which the ray makes with the ſame perpendicular on the other ſide *.

The angle of reflexion being thus in all caſes equal to the angle of incidence, it is evident that the power which cauſes this reflexion is always the ſame. No ſurface however has hitherto been found, which has not ſome inequalities in it to be diſcovered by the microſcope, and yet theſe inequalities do not affect the law thus diſcovered of reflected rays. It is therefore univerſally concluded, that the power which produces this effect in the direction of the rays acts at ſome diſtance from the reflecting ſurface. Innumerable conjectures have been propoſed to explain this phenomenon, but it muſt be confeſſed that even the ſagacity of a Newton was unable to develope and fully explain this reflecting power. He however attributes it to the general principle of repulſion.

A ray of light falling perpendicularly on a plane ſurface is reflected back exactly in the ſame direction in

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* See note on the beginning of Chap. I. and Plate V. fig. 1. The angle of reflexion will alſo be found equal to the angle of incidence on plane ſurfaces, if meaſured from the reflecting ſurface, which is indeed very common in books of philoſophy and treatiſes on optics.

in which it came to the reflecting ſurface; rays falling obliquely obſerve the general law of reflexion, and their angle of reflexion is exactly equal to the angle of incidence. In Plate V. (fig. 1.) *f c* is a ray of light falling perpendicularly on the plane ſurface *a b*, and it is reflected back exactly in the ſame direction; *e c* is a ray falling obliquely on the ſurface at *c*, and it is reflected in the direction *c d*, making the angle of reflexion *c d* P exactly equal to the angle of incidence *c e* P, as may be ſeen by the inſpection of the figure *.

Parallel rays falling obliquely on a plane reflecting ſurface are reflected parallel, converging rays are reflected with the ſame degree of convergence, and diverging rays equally diverging. In other words, plane ſurfaces or mirrors make no change in the natural diſpoſition of the rays of light.

A mirror is a body the ſurface of which is poliſhed to ſuch a degree as to reflect moſt copiouſly the rays of light. In Plate V. fig. 1, 2, 3, are plane mirrors: in fig. 2, the rays *d b* and *c a*, which are parallel, after having reached the ſurface *a b* are reflected, the one towards *b* and the other towards *k*, and in both inſtances the angle of reflexion is evidently equal to the angle of incidence.

The rays *d b* and *c a* (fig. 3.) are convergent, and without the interpoſition of the mirror would unite in the point E; but being reflected they unite in the oppoſite point F, the angle of reflexion with reſpect to each being ſtill equal to the angle of incidence, as may be ſeen by drawing perpendiculars to the points *a* and *b*.

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* The reader will ſee that the angles *d c b* and *e c a*, made with the lines of incidence and reflexion and the reflecting ſurface, are alſo equal.

The rays *d b* and *c a* (fig. 4.) are on the contrary divergent, and after reflexion towards *b* and *k* preſerve exactly the ſame diſtance from each other, as they would have had if they had proceeded without interruption towards F and E, the angle of reflexion being with reſpect to each ray ſtill exactly equal to the angle of incidence.

Thus it is that plane ſurfaces reflect the rays of light; but the effects are materially different when the ſurfaces are convex or concave, though the ſame law ſtill obtains with reſpect to theſe. From a convex ſurface parallel rays when reflected are made to diverge; convergent rays are reflected leſs convergent, or are even made to diverge in proportion to the curvature of the ſurface compared with their degree of convergence; and divergent rays are rendered more divergent. Thus it is the nature of convex ſurfaces to ſcatter or diſperſe the rays of light, and in every inſtance to impede their convergence. From a concave ſurface, on the contrary, parallel rays when reflected are made to converge; converging rays are rendered more convergent; and diverging rays are made leſs divergent, or even in certain caſes may be made to converge.

To underſtand this part of the ſubject, it is neceſſary to be aware that all curvilinear ſurfaces are compoſed of right lines infinitely ſhort, or *points*; and the reader will recollect that only thoſe rays which fall perpendicularly on a reflecting ſurface are reflected back in the ſame direction. All curves are arches or ſegments of circles; if therefore any curvilinear or ſpherical ſurface is preſented to a number of parallel rays, it is evident that only that ray which ſtrikes the ſpherical ſurface in ſuch a direction that it would proceed in a right line to the center of that circle, of which the reflecting

flecting ſurface is an arch or ſegment, can be ſaid to fall perpendicularly upon it, of which the reader may convince himſelf by drawing a ſtrait line with a ruler at any point of a given circle or curve. All the reſt of the parallel rays therefore falling on the ſpherical ſurface will fall obliquely upon it, and will conſequently be ſubject to the general law of reflexion, and the angle of their reflexion will be equal to the angle of their incidence.

Perhaps the ſubject will be rendered ſtill plainer if, purſuing the idea thrown out in the preceding paragraph, that all curves are formed of a number of ſtrait lines infinitely ſhort, and inclining to each other like the ſtones in the arch of a bridge, I preſent to the reader the figures 5, 6, 7, which may be imagined ſo many mirrors bent or inclined in the form which is repreſented in the plate. The rays *a b* and *c d* (fig. 5.) which are parallel, are from their different points of incidence rendered divergent in *b* and *e*: the angle of reflection with reſpect to each being equal to the angle of incidence.

In figure 6 the rays *a b* and *c d* are convergent, and would without the interpoſition of the reflecting ſurface *b d* unite in *m*; but according to the ſame principle they now proceed to unite in *l*, which is more diſtant from the reflecting ſurface than the point *m*; and it is evident, that if the curvature of the two branches of the reflecting ſurface *b* and *d* was greater they might be reflected parallel or even divergent. In the ſame manner in fig. 7, the rays *a b* and *c d* which, without the interpoſition of the convex ſurface *b d*, would diverge but very little at *m*, become after reflexion much more divergent at *l*; and the angles of reflexion will be found in all theſe caſes exactly equal to the angles of incidence, if meaſured from the reflecting

flecting ſurface produced or lengthened, as at *f g* and *i k*.

Let now figure 8 repreſent a concave mirror formed upon the ſame principles as thoſe which we have been examining of the convex kind. The rays *a b*, *c d*, which were parallel before reflexion, and which make their angles of reflexion equal to their angles of incidence (meaſured for convenience in this figure from the reflecting ſurface produced) become evidently convergent at the point *l*; upon the ſame principles in fig. 9, the converging rays *a b* and *c d*, which would not have united before they reached the point *m*, are now after reflexion united at *l*, which is much nearer the reflecting ſurface. In fine, the divergent rays *a b* and *c d* in fig. 10, which would have become more divergent at *m*, had they not been intercepted by the reflecting ſurface, become convergent after reflexion, and are found actually to unite at *o*.

Mirrors are formed either of metal or of glaſs, which is plated behind with an amalgam of mercury and tin. The latter are moſt in common uſe, but they are improper for optical inſtruments, ſuch as teleſcopes, &c. becauſe they commonly preſent two images of the ſame object, the one vivid and the other faint, as may be perceived by placing the flame of a wax taper before a common looking-glaſs. The reaſon of this double image is, that a part of the rays are immediately reflected from the anterior ſurface of the glaſs, and thus form the faint image, while the greateſt part of the rays penetrating the glaſs are reflected by the amalgam, and form the vivid image.

From the principles laid down in the courſe of this chapter, moſt of the common phenomena of reflexion may be explained. In PLANE MIRRORS the image appears of its natural ſize, and at the ſame diſtance be-

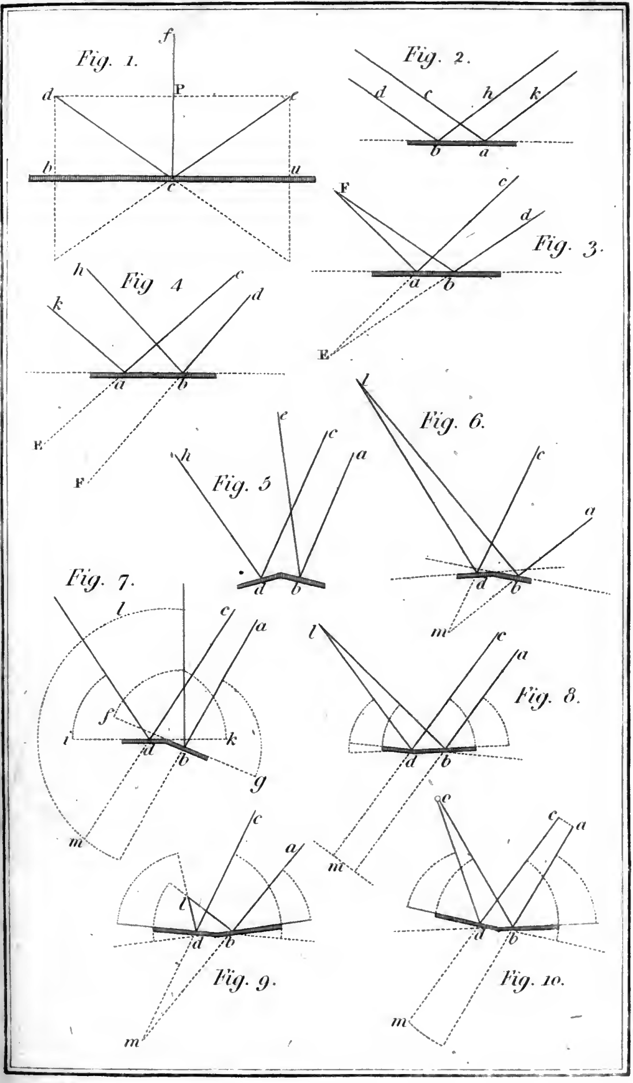
Fig. 1.
f
P
d
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b
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Fig. 2.
d
c
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Fig. 3.
F
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Fig 4
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Fig. 6.
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Fig. 7.
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Fig. 8.
l
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Fig. 9.
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Fig. 10.
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hind the glaſs as the object is before it. To underſtand perfectly the reaſon of this, it will be neceſſary to advert to the ſubject of viſion as explained formerly in a note. It will be remembered, that by the ſpherical form of the eye, and particularly by means of the cryſtalline humour which is placed in the middle of it, the rays of light are converged, and thoſe from the extreme points of the object croſs each other, ſo as to form an inverted image on that part of the optic nerve which is 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.

As therefore the angle of reflexion is always equal to the angle of incidence, it will be evident on the inſpection of Plate VI. fig. 1, that the converging rays K *m*, L *n*, proceeding from the extremities of the object K L, and falling on the mirror *a b*, are reflected to the eye at *e* with the ſame degree of convergence, and conſequently will cauſe the image *k l* to be ſeen under an angle equal to that under which the object itſelf would have been ſeen from the point *i* without the interpoſition of the mirror. The image appears alſo at a diſtance behind the mirror equal to that at which the object ſtands before it. For it muſt be remembered, that objects are rendered viſible to our eyes not by a ſingle ray proceeding from every point of an object, but that in fact pencils or aggregates of divergent rays proceed from every point of all viſible objects, which rays are again by the mechaniſm of the eye converged to a point on all thoſe parts of the retina where the image is depicted. The point from which the rays diverge is called the *focus of divergent rays*, and the point behind a reflecting ſurface from which they appear to diverge is called the *vir-*

tual focus. As therefore the angle of reflexion is exactly equal to the angle of incidence, it is evident, that the virtual focus will be at the ſame diſtance behind the mirror as the real focus is at before it. Thus in fig. 2, the diverging rays *c b* will after reflexion appear to diverge from the point *g* which is behind the mirror *a b*, and that point for the reaſons aſſigned (viz. no alteration being made in the diſpoſition of the rays but only in the direction) will be at an equal diſtance behind the mirror with the luminous point *c* before it.

As every part of the image appears at a diſtance behind the mirror equal to that at which the object ſtands before it, and as the object K L (fig. 1.) is inclined or out of the vertical poſition, the image *k l* appears alſo inclined. Hence it is evident, that to exhibit objects as they are without any degree of diſtortion, looking-glaſſes ſhould be always hung in a vertical poſition, that is, at right angles with the floor of the apartment.

It is clear, however, from what has preceded, that the caſe muſt be very different with thoſe mirrors, the ſurfaces of which are ſpherical, whether convex or concave. Of the former, it has been ſhewn that their property is to ſcatter and diſperſe the rays of light, to render thoſe divergent which were parallel, to diminiſh the convergence of converging rays, and to augment the divergence of thoſe which diverged before. The firſt obvious effect of theſe mirrors, therefore, muſt be to exhibit the image of the object which is oppoſed to them ſmaller than it is in reality. For the angle under which the rays ſtrike the eye of the obſerver, muſt neceſſarily be ſmaller in proportion to the convexity of the mirror. Suppoſe, for inſtance, the object C D, Plate VI. fig. 3, placed before the convex

convex mirror *a b*; the two rays C *e* and D *d*, which proceed from the extremities of the object, and which, without the interpoſition of the mirror, would converge at *f*, are reflected leſs convergent, and unite at *i*, forming an angle much more acute than they would otherwiſe have done. The conſequence, therefore, of the viſual angle being ſo much more acute is, that the image *g b* is proportionably ſmaller than the object itſelf.

The ſecond effect of this diſperſion of the rays is, that the image appears at a leſs diſtance behind the glaſs than it would have done in a plane mirror. To underſtand this effect, it is neceſſary again to advert to a principle of optics, which has been juſt ſtated, viz. that objects are rendered viſible not by a ſingle ray of light proceeding from every point of the object, but that from every minute point of the ſurface of every viſible object pencils of divergent rays proceed, which are again converged on the retina of the ſpectator's eye.

Suppoſe then G (fig. 4.) a luminous point of any viſible object, from which a pencil of divergent rays proceed, and fall upon the convex mirror *a b*. Theſe rays, agreeably to the nature of theſe mirrors, are reflected more divergent, and have their fictitious point of re-union (or virtual focus) *g* much nearer to the eye and to the ſurface of the mirror than they would otherwiſe have. The image, therefore, as may be ſeen in the figure, inſtead of being at a diſtance behind the mirror equal to the diſtance at which the object ſtands before it (as would be the caſe in a plane mirror) will appear at a ſmaller diſtance, and this diſtance will always be diminiſhed in proportion to the convexity of the mirror.

For the ſame reaſons an object of a certain ſize, placed either perpendicularly or obliquely before a convex mirror, will neceſſarily appear curved or bent, becauſe the different points of the object are not at equal diſtances from the ſurface of the mirror. All theſe effects will be very apparent from inſpecting one of thoſe ſmall glaſs globes, lined with the common amalgam for making looking-glaſſes, which are ſometimes ſuſpended in old-faſhioned apartments. In theſe the company ſeated in the room, or round the table, are repreſented by very minute images, which appear not at a certain diſtance behind as in plane looking-glaſſes, but very near the ſurface of the mirror, and always in ſome degree curved or diſtorted.

The effects and phenomena of CONCAVE MIRRORS will obviouſly, from what has been ſaid, be the direct contrary to thoſe of the convex kind. The ſurface of concave mirrors is generally ſpherical (or in the form of a globe) though that is not always the moſt convenient form for optical purpoſes, but it is that which is leaſt difficult to the workmen.

The general effect of concave mirrors is, we have already ſeen, to render the rays more convergent. The point in which the converged rays unite is called the focus of converging rays, but this focus cannot be the ſame for all the rays incident on a concave ſurface. The parallel rays *a b*, *d e* (fig. 5.) are converged by the mirror at the point F, which is diſtant from the mirror one-fourth part of the diameter of that circle, of which the mirror is a part or ſection; and this is the point which is called the *focus of parallel rays*, and it is the real or *principal focus* of the mirror. The converging rays *f g*, *h i*, are reflected upon the ſame principles more convergent, and unite at the point K, nearer to the ſurface of the mirror than the principal focus. In fine, the divergent rays R *m* and R *o*, which proceed from the point R, beyond the principal focus, unite

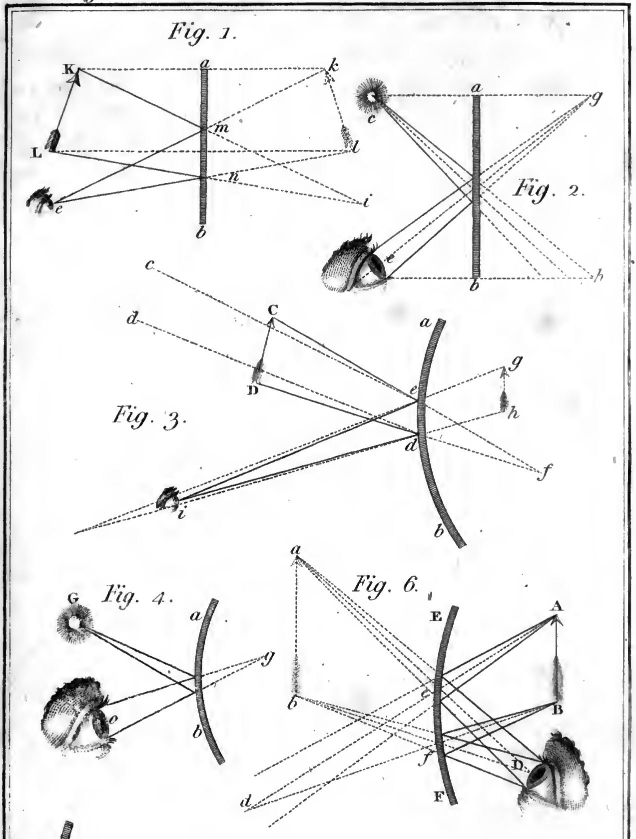
Fig. 1.
K
a
k
m
L
l
n
e
i
b
Fig. 2.
c
a
g
e
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h
Fig. 3.
c
d
C
a
D
e
g
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d
f
i
b
Fig. 4.
G
a
g
e
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Fig. 6.
a
E
A
c
b
B
f
D.
d
F
Fig. 5.
m
f
b
a
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o
h

unite at the point P. But if the point of divergence was nearer the mirror than the principal focus, as for inſtance at K, they would ſtill be reflected divergent, and would proceed one towards *f* and the other towards *b*.

Plane and convex mirrors exhibit, as has been already mentioned, the image behind the glaſs or mirror, and in a ſituation conformable to that of the object; but concave mirrors produce this effect only when the object is placed between the principal focus and the mirror, and then the image is larger than the object. Let A B (fig. 6.) be the object placed before the concave mirror E F, and nearer to the mirror than its principal focus. The two rays A *e*, B *f*, which proceed from the extremities of the object, and which, without the interpoſition of the mirror, would converge at *d*, are reflected more converging, and unite at D; and making an angle greater or more obtuſe than they would otherwiſe have done, the image *a b* is conſequently greater than the object.

This image too appears at a greater diſtance behind the mirror than the object is at before it. The reaſon of this will appear, if we ſuppoſe A (Plate VII. fig. 1.) a point of any object placed nearer to the mirror than the principal focus F, whence a pencil of divergent rays proceeds, and falling on the mirror, are (accordcording to the principles before laid down) reflected leſs divergent, and conſequently have their virtual or imaginary focus at a greater diſtance than if the object had been placed before a plain mirror.

If, on the contrary, the object is placed farther from the mirror than the principal focus, as for inſtance at *e*, the rays *e b*, *e d*, being only moderately divergent, when they come in contact with the mirror, are reflected convergent, and will repreſent at E an image of the object. If the eye, therefore, is withdrawn to a ſufficient diſtance (to *o* for example) for the rays to croſs each other, it will perceive the image at E between the mirror and itſelf. The reaſon of this depends upon what has been already ſtated. Every object is rendered viſible to us by pencils of divergent rays from every point of that object; it therefore ceaſes to be viſible if theſe rays become parallel or convergent; and this happens when the object is not nearer to the mirror than the principal focus. To render, therefore, an object thus ſituated viſible, it is neceſſary that the eye ſhould recede ſo far beyond the place of the image E, as to allow the rays to croſs each other, and meet the eye in a ſtate of divergence.

The image is in this caſe always inverted. Such is the image *b a* of the object A B (fig. 2.) From this property of the concave reflector to form the image of an object, in theſe 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 mirror, 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 of 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.

Since it is the property of a concave mirror to cauſe thoſe rays which proceed in a parallel direction to its ſurface to converge to a focus, and ſince the ſolar rays, from the immenſe diſtance of that body, may be conſidered as parallel, concave mirrors prove very uſeful burning-glaſſes, and the focus of parallel rays, or principal focus, is their focus or burning point.

CYLINDRICAL MIRRORS, ſuch as that repreſented in figure 3, are employed more for the purpoſe of amuſement than of philoſophy. They are called mixed mirrors, becauſe they produce at the ſame inſtant the effects of plain and of convex mirrors. Suppoſe, for inſtance, G F (fig. 4.) to be the height of ſuch a mirror, and A E an object placed before, or rather below it; all the rays, which proceed from the points A, B, C, D, E, falling on the ſurface G F of the mirror, and reflected to the eye at O, will repreſent the images of theſe different points at *a*, *b*, *c*, *d*, *e*, as they would be repreſented in a plane mirror; and with reſpect to theſe the dimenſions of the object will not be altered in the correſponding image. But ſince the mirror is alſo curved, if we ſuppoſe the ſpace *q*, *t*, *y* (fig. 5.) to repreſent a part of its circumference, the rays A *q*, L *r*, M *s*, N *t*, O *x*, P *z*, F *y*, being reflected to the eye

eye at Z, will exhibit all theſe points A, L, M, N, &c. within the ſpace *a f*, which will in this direction diminiſh conſiderably the dimenſions of the image, according to the principles already explained in treating of the convex mirror *. The ſame will take place with reſpect to all the points of the object which are viſible within the lines B Q G, C R H, D T I, E S K, concentric to the ſurface of the mirror. Theſe parts muſt therefore be very much extended in the drawing or deſign, if a perfect image is to be repreſented in the mirror. Diſtorted drawings of this kind are common in the ſhops of the opticians, which, on a cylindrical mirror being placed on the board or drawing, diſplay perfect figures. The principle of theſe will, however, be very eaſily underſtood from what has been now ſtated.

The CONICAL MIRROR is repreſented in fig. 6, and this is alſo conſidered as a mixed mirror; for, as well as the cylindrical, it produces at once the effects of a convex and a plane mirror. Suppoſe, for inſtance, the angle C K F (fig. 7.) to repreſent this mirror, and the lines C K, F K, two of the right lines which compoſe it. Theſe two lines would then anſwer to two plane mirrors inclined towards each other, and the rays proceeding from the points A, B, C, falling on the ſurface at *g*, *h*, *i*, and reflected towards the eye at O, would repreſent theſe points as if at the baſe of the mirror in the oppoſite order *a*, *b*, *c*; and the ſame obſervation will apply to the points D, E, F, which are repreſented at *d*, *e*, *f*, as well as all thoſe which are in the circles A H D, B I E, C G F. But

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* *Viz.* by diminiſhing the convergence of rays, and conſequently reducing the ſize of the image in proportion to the convexity. In the cylindrical mirror, it muſt be obſerved, that it is in the breadth only that this diminution takes place.

Plate 7.

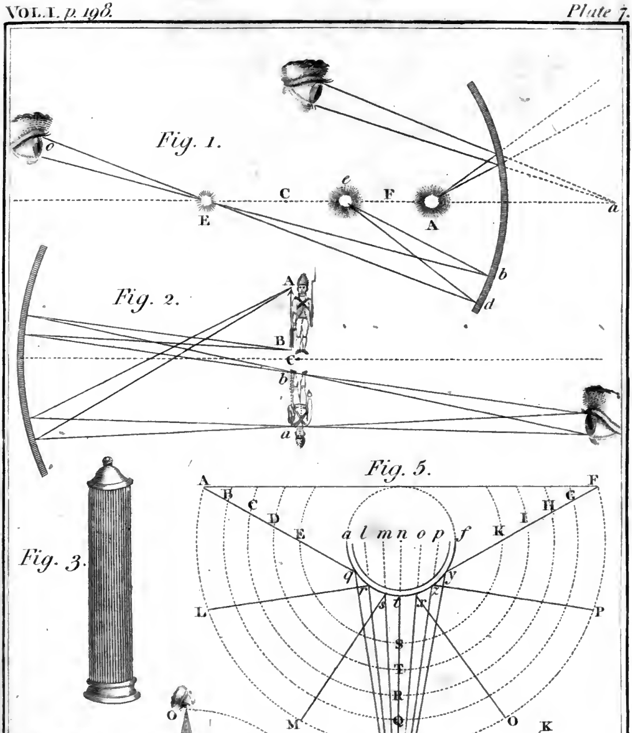
Fig. 1.
o
E
C
e
F
A
a
b
d
Fig. 2.
A
B
C
b
a
Fig. 3.
Fig. 5.
A B C D E
F G H I K
a l m n o p f
q r s t x z y
L
P
S T R Q N
M
O
Z
Fig. 6.
Fig. 7.
O
K
g
h
i
A B C c b a d e f F E D
G
I
H
K
O
F
h
g
Fig. 4.
a b c d e G E D C B A

as there do not proceed from each point ſimple rays of light, but pencils of rays, they are modified in this mirror upon the ſame principles as in the convex mirror, and conſequently the image will appear ſmaller than the object, and nearer to the eye than in the plane mirror.

Hence it will be evident, that we may ſee in the center the image of whatever is painted on the exterior circumference A H D, and the extremities of the image will be formed from the interior circle C G F; and as the curvature or convexity of the mirror is greater towards the apex or point of the cone, it follows, that that which is the moſt extended in the object will be the moſt compreſſed or concentrated in the image. Thus the dark part of the board (Plate VIII. fig. 1.) is intended to repreſent in the mirror an ace of ſpades; and the points *a*, *b*, *c*, *d*, *e*, *f*, *g*, &c. which are neareſt to the mirror, form the outer circumference of the image, and the points 1, 2, 3, 4, 5, 6, 7, 8 of the external circumference of the board unite in the center of the image almoſt at an imperceptible point.

CHAP. IV.

GENERAL VIEW OF THE PHENOMENA OF REFRACTION.

Laws of Refraction.—Degree of Refraction which Light ſuffers from different Mediums.—Common Phenomena of Refraction.—Refraction by ſpherical Surfaces—By convex Surfaces—By concave Surfaces.—Of Lenſes.—Convex Lenſes.—Concave Lenſes.—Different Refrangibility of the Particles of Light.—Experiment with the Priſm.

IT has been proved that light, like every known ſubſtance, is ſubject to the laws of attraction; it has been intimated too, that even its propenſity to move in a direct line is, in certain caſes, overcome by this ſuperior influence; and that the direction of the rays of light is changed in paſſing from one medium to another. The ſpace in which a ray of light moves is called a medium, whether pure ſpace, air, water, glaſs, or any other tranſparent ſubſtance; and when a ray is bent out of its natural courſe in paſſing from one medium to another, it is ſaid to be *refracted* or broken, probably from the broken appearance which a ſtaff, &c. exhibits when part of it is immerſed in water.

There are two circumſtances eſſential to refraction; 1ſt, That the rays of light ſhall paſs out of one medium into another of a different denſity, or of a greater or leſs degree of reſiſtance. 2dly, That they paſs in an oblique direction.

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,

denſity, that which is of an oily or inflammable nature will have a greater refracting power than the other.

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, that is, ſo that the angle of refraction ſhall be leſs than the angle of incidence; 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. Thus, in paſſing from empty ſpace into air, or any other medium whatever, the ray is bent towards the perpendicular, and in paſſing from any other medium into pure ſpace, it is bent the contrary way, that is, from the perpendicular; the ſame effects will take place in paſſing from air into glaſs, and from glaſs into air, &c.

To render this perfectly clear, let us have recourſe to Plate VIII. fig. 2. If a ray of light *p* C paſſes from air into water, in the direction *p* C, perpendicular to the plane D *d*, which ſeparates the two mediums, it ſuffers no refraction, becauſe one of the eſſentials is wanting to that effect, viz. the obliquity of the incidence.

But

But if a ray A C paſſes obliquely from air into water, inſtead of continuing its courſe in the direct line C B, it takes the direction C *a*, and approaches the perpendicular *p* P, in ſuch a manner that the angle of refraction P C *a* is leſs than its angle of incidence *p* C A.

If the ray came in a more oblique direction, the refraction would be ſtill greater; ſo that in all caſes, where the mediums are the ſame, the angle of refraction will always be found to bear a regular and conſtant proportion to the angle of incidence; or, to ſpeak in technical language, 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.

The refraction of light, we have already ſeen, is attributed by Sir Iſaac Newton to the principle of attraction; and perhaps one of the moſt ſatisfactory proofs of this theory is the known fact, that the change in the direction of the ray commences, not when it comes in contact with the refracting medium, but a little before it reaches the ſurface, and the incurvation augments in proportion as it approaches this medium. Indeed no principle will account for the phenomenon of light paſſing more eaſily, that is, more directly, through a denſe than through a rare medium, but that of at-

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* There are ſome differences in the refractive powers of different glaſſes, according to the nature of the materials; but theſe are too minute to deſerve notice in treating of general principles.

traction, ſince it is found by univerſal experience, that the attraction of all bodies is in proportion to their denſities.

In paſſing from a denſe into a rare medium, however, there is a certain degree of obliquity at which the refraction is changed into reflection. In other words, a ray of light will not paſs out of a denſe into a rare medium, if the angle of incidence exceeds a certain limit, but will be reflected back. Thus a ray of light will not paſs out of glaſs into air, if the angle of incidence exceeds 40° 11, or out of glaſs into water, if the angle of incidence exceeds 59° 20.

As the rays of light, in paſſing from a denſe medium to a rarer, are refracted *from* the perpendicular, in fact are bent or inclined towards the eye of the ſpectator, who looks at an object in the denſer medium while ſtanding at its ſide, the reaſon will be clear 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. 3.) 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 *m a* will appear to make an angle with the part Q*m*. On this account alſo, a fiſh in the water appears much nearer the ſurface than it actually is; and a ſkilful markſman, in ſhooting at it, will aim conſiderably below the place which it ſeems to occupy.

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

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* If the ſpectator ſtands on a bank, juſt about the level of the water, it is about one-third deeper than it appears.

the

the baſon; then by pouring water into the baſon, the ſhilling inſtantly appears; for by what has been ſaid above, the object, being now in a denſer medium, is made to appear nearer to its ſurface.

As the refraction muſt in all caſes depend on the obliquity of the ray, that part of any body which is moſt immerſed will ſeem to be moſt materially altered by the refraction. When, however, the object extends to no great depth in the water, the figure is not materially diſtorted; but if the object is of a conſiderable ſize, or extends to a great depth, thoſe rays which proceed from the more diſtant extremities come in a more oblique direction on their emergence into the air, and they conſequently ſuffer a greater refraction than the reſt. Thus a ſtrait leaden pipe appears near the bottom of a deep water to be curved, and a flat baſon ſeems deeper in the middle than near the ſides.

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 ſomething 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.

Parallel rays, if refracted, preſerve their parallel direction both in entering and in paſſing out of a refracting medium, provided the two ſurfaces of the refracting medium are parallel. The two rays, E A, E A, (fig. 4.) after refraction, while they approach the perpendiculars *p p*, continue parallel as before, the reaſon of which is evident on the principles already eſtabliſhed,

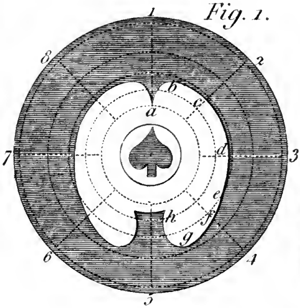

Fig. 1.

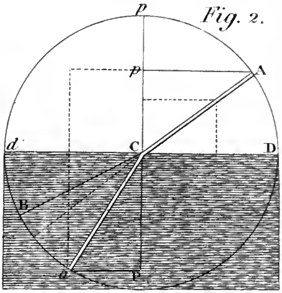

Fig. 2.

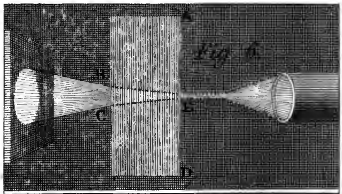

Fig. 6.

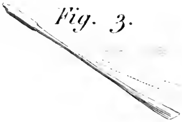

Fig. 3.

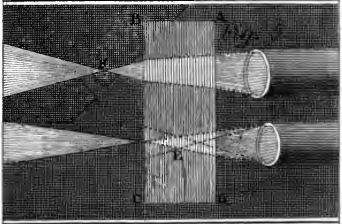

Fig. 5.

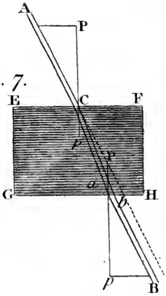

Fig. 7.

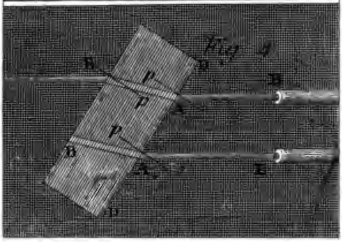

Fig. 4.

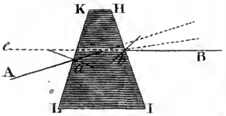

Fig. 8.

ed, for the ray A C, (fig. 7.) on coming in contact with the ſurface of the refracting medium E F, does not continue its courſe in the ſtrait line C *b*, but being refracted at the point of contact C, it approaches the perpendicular P *p*, and comes out at *a*.

After coming out of the refracting medium, if we ſuppoſe the ſurface G H parallel to E F, it ought to proceed to B, having deviated from the perpendicular in the ſame degree in which it approached it on its firſt refraction, and thus it continues parallel to the line C B, which is that in which it would have proceeded, if it had not been intercepted by the medium.

This paralleliſm cannot ſubſiſt if the two ſurfaces K L, H I, (fig. 8.) are inclined, as in the figure, becauſe the ray entering at *a*, and emerging at *b*, the object A will be ſeen from the point B at *e*, which is out of its true place.

Converging rays become leſs convergent in paſſing from a rare to a denſer medium, as from air into water; and on the contrary, their convergence is augmented by paſſing from a denſe to a rarer medium, as from water into air. (See fig. 5.) In the ſame manner, diverging rays become leſs divergent in paſſing out of a rare medium into one which is denſer, and their divergence is increaſed by paſſing out of a denſe into a rarer medium. (See fig. 6.) This fact is a neceſſary conſequence of the general law of refraction; but it will ſatisfactorily explain why an object under water appears larger to an eye above the ſurface than it really is; and why all objects appear magnified ſeen through a miſt; for in all theſe caſes, the converging rays, by which we ſee the extreme points of the object, and which during their paſſage through the water, &c. were refracted towards the perpendicular, on their emergence into the air are made more ſuddenly to converge,

converge, and conſequently the viſual angle is rendered more obtuſe.

It is evident, that when *parallel* rays fall upon a SPHERICAL SURFACE, that ray only which penetrates to the center or axis will proceed in a direct courſe, for all the reſt muſt neceſſarily make an angle more or leſs obtuſe, in proportion to their diſtance from the center *; they are therefore rendered convergent or divergent according to the nature of the medium on which they are incident. If they fall on the CONVEX SURFACE of a medium *denſer* than that which they leave, as in paſſing from air into glaſs, they will converge, as may be ſeen in Plate IX. fig. 1. where that phenomenon is repreſented; for the parallel rays, *b i*, *f g*, (fig. 6.) falling in an oblique direction on the refracting medium, terminated by the convex ſurface E *i g*, they will be refracted, and will each reſpectively approach the perpendiculars *i* C, or *g* C, and will conſequently have a tendency to unite towards the axis A B.

It is however proper to remark, that the point at which they join the axis A B will be diſtant from the ſurface of the refracting medium in proportion as the point on which they fall on the convex ſurface is diſtant from that axis, becauſe the more diſtant that point is, the more oblique is the incidence of the ray. Thus the ray *b i* joins the axis at *k*; but the ray *f g* does not meet it till it arrives at D.

Rays already *convergent*, falling on the convex ſurface of a denſe medium, will be acted upon differently according to circumſtances.

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* See what was obſerved on this ſubject in the preceding chapter, p. 188.

If

If their convergence is exactly proportioned to the convexity of the ſurface, they will not ſuffer any refraction; (ſee fig. 2.) becauſe in that caſe one of the eſſentials is wanting to refraction, viz. the obliquity of the incidence, and each ray proceeds in a direct line to the center of that circle, of which the convex ſurface is an arch or ſegment. For inſtance, the rays *ef*, and *dh*, (fig. 7.) which tend to unite at C, the center of the convex ſurface, may be conſidered as perpendicular, being the *radii* of the circle.

If the rays have a tendency to converge before they reach the center of the convexity, they will then be rendered leſs convergent; for inſtead of converging to a point at *b* (fig. 3.) they will converge at B. The reaſon of this is evident, for the ray *ih* (fig. 7.) which, if not intercepted, would meet the axis at *k*, nearer the ſurface of the refracting medium than the center of convexity C, being refracted towards the perpendicular or radius *d*C, meets the axis only at *o*.

If, on the contrary, the rays have a tendency to converge beyond the center of the convexity, they will then, by the law of refraction, be rendered ſtill more convergent, as in fig. 4, where their point of union, if not intercepted, would be *c*, but where, by the influence of the refraction, they are found to converge at C. For the ray *gb* (fig. 7.) the tendency of which is towards *l*, is refracted towards the perpendicular *d*C, and joins the axis at *p*.

If *diverging* rays fall on the convex ſurface of a denſer medium, they are always rendered leſs divergent, as in fig. 5.; and they may be rendered parallel, or even convergent, according to the degree of divergence compared with the convexity of the refracting ſurface, on the principles already explained.

If rays paſs from a *denſe* to a *rarer* medium, the ſurface of the denſe medium being convex *, in this caſe *parallel* rays become convergent; for the parallel rays *de*, *gi* (fig. 8.) when they reach the convex ſurface *e* D *i*, inſtead of continuing their direct courſe, are refracted from the perpendiculars *a*C, *b*C, and converge at *k*.

Converging rays are alſo rendered more convergent. Thus the rays *le*, *ni*, which, without any change in the medium, would have proceeded in the direction *m* and *o*, in conſequence of the refraction which they ſuffer, and which bends them from the perpendiculars *a* C, *b* C, unite at *p*.

Diverging rays, if they proceed from the point C, the center of convexity, ſuffer no refraction, becauſe, for the reaſons already aſſigned, they may be conſidered as perpendicular to the refracting ſurface, and conſequently they are deficient in one of the cauſes of refraction, the obliquity of incidence.

If they proceed from a point which is nearer to the ſurface than the center of convexity, ſuch as *r*, they will be refracted from the perpendiculars *a*C, *b*C, and will be rendered more divergent towards *x* and *y*.

If, on the contrary, the diverging rays come from a point, ſuch as *q*, beyond the center of convexity, they will be rendered leſs divergent, for inſtead of going towards *z* and *z*, they will be refracted from the perpendiculars *a* C, *b* C, towards *f* and *h*.

When rays paſs from a *rare* into a *denſe* medium, and the ſurface of the denſe medium is CONCAVE, then *parallel* rays are rendered divergent, as in Plate X. fig. 1. for the parallel rays *a b*, *d e* (fig. 5.) are refracted

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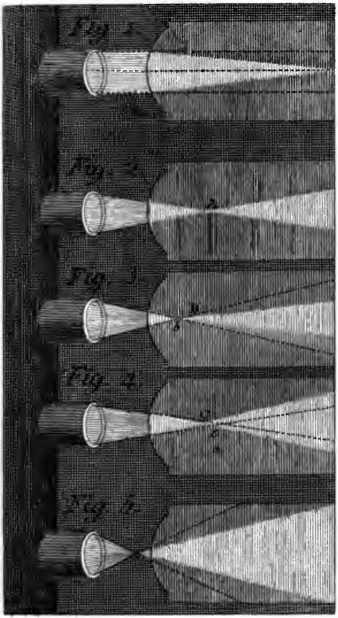
* The ſurface of the rare medium conſequently being concave.



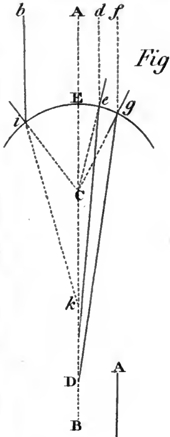


Fig. 6.

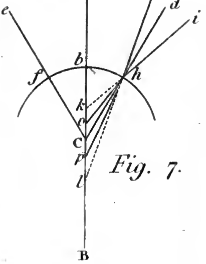


Fig. 7.

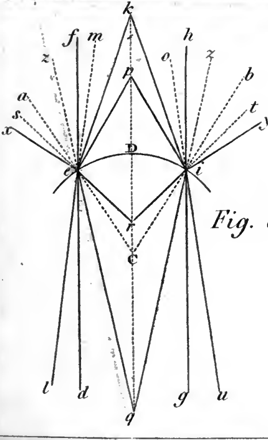


Fig. 8.

towards the perpendiculars *f* C and *g* C; and are conſequently divergent.

Converging rays falling on the ſame concave ſurface will be rendered leſs convergent, as in fig. 2. For the rays *a b*, *d e* (fig. 6.) which would have converged at O, if their progreſs had not been intercepted, will be refracted towards the perpendiculars *f* C and *g* C, and will unite only at *i*. If the convergence was leſs, they might by the refraction be rendered parallel or even divergent.

Diverging rays proceeding from the center of concavity will not ſuffer any refraction, for the reaſons already aſſigned.

If, however, diverging rays proceed from any point nearer the refracting ſurface than the center of concavity, they will be rendered leſs divergent, as in fig. 3. For the two diverging rays *k b* and *k e* (fig. 7.) inſtead of proceeding to *d* and *h*, are refracted towards the perpendiculars *f* C and *g* C.

If, on the contrary, which is the moſt general caſe, the diverging rays proceed from a point more diſtant from the ſurface than the center of concavity, their divergence will be increaſed as in fig. 4. For the diverging rays *l b* and *l e* (fig. 7.) which tend towards *m* and *n*, are refracted towards the perpendiculars *f* C and *g* C, and become more divergent than they would otherwiſe have been.

When rays paſs from a *denſe* into a *rarer* medium, and the denſe medium is terminated by a concave ſurface, then

Parallel rays become divergent; for the parallel rays *d e*, *g i* (fig. 8.) when they reach the concave ſurface *e* D *i*, inſtead of continuing their courſe in the direct lines towards *f* and *h*, proceed towards *m* and *p*, being

refracted

refracted from the perpendiculars C *a*, C *b*, and are conſequently divergent.

Converging rays, if their point of convergence is preciſely at C, the center of the concavity *e* D *i*, will not ſuffer any refraction, becauſe they are perpendiculars, as already explained, therefore have no obliquity of incidence. If, on the other hand, the rays tend to a point, ſuch as *n*, nearer to the ſurface than the center of the concavity C, then they are rendered more convergent, for the rays *q e*, *r i*, which naturally tend to that point, are refracted from the perpendiculars C *e*, C *i*, and converge at *o*, nearer the concave ſurface.

Laſtly, if the converging rays tend to a point *l*, which is beyond the center C, they are rendered leſs convergent. For the rays *s e*, *t i*, which would naturally unite at that point, are refracted from the perpendiculars C *e*, C *i*, and unite at *k*, which is more diſtant ſtill.

Diverging rays in the ſame circumſtances are rendered more divergent. For the rays E *e*, E *i*, diverging from the point E, inſtead of proceeding towards *u* and *x*, are refracted from the perpendiculars, and are directed towards *y* and *z*.

From the property which all ſpherical convex ſurfaces have of rendering parallel rays paſſing out of a rarer medium convergent, glaſſes made in this form are very commonly uſed as burning glaſſes; and as the ſun's rays, proceeding from ſo vaſt a diſtance, may be conſidered as parallel, the *focus* of parallel rays will of courſe be their burning point.

A LENS is a tranſparent body of a different denſity from the ſurrounding medium, and terminated by two ſurfaces, either both ſpherical, or the one plane and the other ſpherical, whether convex or concave. They are therefore generally diſtinguiſhed by their forms, and

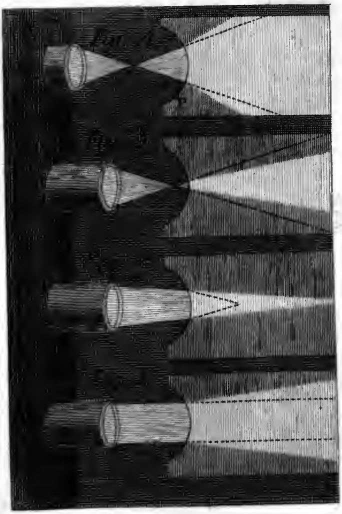


Fig. 4.

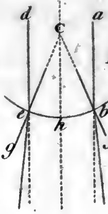
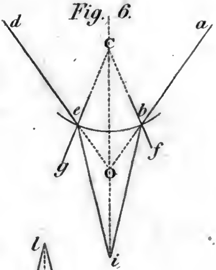


Fig. 5.

Fig. 6.



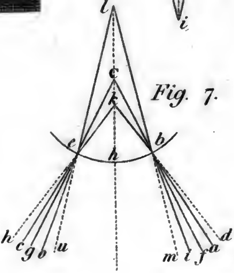


Fig. 7.

Fig. 8.

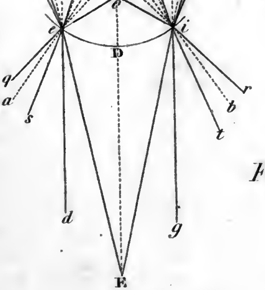
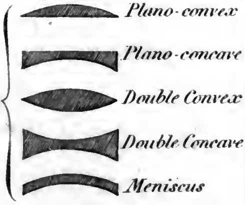
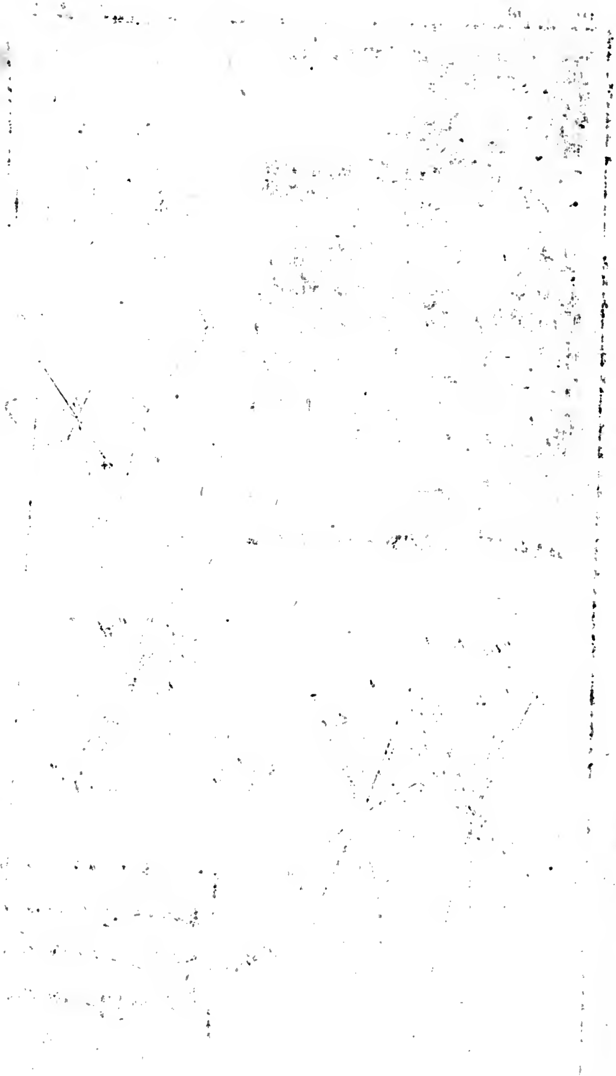


Fig. 9.





and are called plano-convex, or plano-concave; or double convex or double concave; a lens which has one ſide convex and the other concave, is called a meniſcus, or concave-convex lens. See Plate X. fig. 9.

It is evident that in lenſes there may be almoſt an infinite variety with reſpect to the degree of convexity or concavity, for every convex ſurface is to be conſidered as the ſegment of a circle, the diameter and radius of which may vary to almoſt an infinite extent. Hence, when opticians ſpeak of the length of the radius as applied to a lens, as for inſtance, when they ſay its radius is 3 or 6 inches, they mean that the convex ſurface of the glaſs is the part of a circle, the radius of which, or half the diameter, is 3 or 6 inches.

The axis of a lens is a ſtrait line drawn through the center of its ſpherical ſurface; and as the ſpherical ſides of every lens are arches of circles, the axis of the lens would paſs exactly through the centers of that circle, of which its ſides are arches or ſegments.

From what has been already ſtated in the former part of this chapter, it is obvious that the certain effect of a CONVEX LENS muſt be to render parallel rays convergent; to augment the convergence of converging rays; to diminiſh in like manner the divergence of diverging rays, and in ſome caſes to make them parallel or even convergent, according to the degree of divergence, compared with the convexity of the lens. In what is called a double convex lens, this effect will be increaſed in a duplicate proportion, ſince both ſurfaces will act in the ſame manner upon the rays; and ſince it has been proved, that parallel or convergent rays have their convergence equally augmented by being incident on the convex ſurface of a denſe, or the concave ſurface of a rare medium. Theſe glaſſes then

muſt

muſt neceſſarily have the effect of magnifying glaſſes, ſince by the convergence of the rays the viſual angle is rendered more obtuſe, and conſequently the image which is depicted on the retina muſt be proportionably larger.

The mode of finding, upon mathematical principles, the focus of parallel rays or principal focus in theſe glaſſes, will be explained in a ſucceeding chapter; and it may be eaſily found, though not with equal exactneſs, by holding a ſheet of paper before the glaſs when expoſed to the rays of the ſun, and obſerving the diſtance of the paper from the glaſs, when the luminous ſpot on the paper is very ſmall, and when it begins to burn; or when the focal length does not exceed three feet, the focus may be found by holding the lens at ſuch a diſtance from the wall oppoſite a window ſaſh, that the image of the ſaſh may appear diſtinct upon the wall. The principal focus, or as it is often called *the focus*, of a double convex lens is at the length of the radius, or ſemidiameter of that circle which is formed by the convexity of either of its ſurfaces.

From this property in convex lenſes of rendering all rays in ſome degree convergent which fall upon their ſurfaces, it is evident that in all ſuch caſes there muſt be a point or focus, where rays proceeding from the extreme point of any object muſt croſs each other; and conſequently an inverted image of the object will be exhibited at any diſtance beyond that point. This may be elucidated by a very eaſy experiment, *viz.* by holding a common reading 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

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.

From the ſame property, convex lenſes will cauſe many rays to enter the eye which would otherwiſe have been ſcattered or diſperſed, and therefore objects ſeen through them appear clearer and more ſplendid, than when viewed by the naked eye. If, however, the glaſs is very thick, ſome of the rays which enter it will be reflected or ſent back, and conſequently the brilliancy of the image will ſuffer ſome diminution.

A large object ſeen through a lens which is very convex, will appear deformed; and this proceeds from the refraction not being equal at all points in ſuch caſes. The ſame cauſe operates alſo to render ſome parts of the image indiſtinct, while others are diſtinct and clear. Thus the extremities of the image ſeen through a lens of a very ſhort focus are commonly confuſed and indiſtinct, becauſe the refraction at the edges of the lens do not agree with that of the middle parts. This defect in optical glaſſes has in ſome meaſure been remedied by the ingenious invention of Mr. Dolland, of which we ſhall have afterwards to treat.

The effects of a CONCAVE LENS are directly oppoſite to thoſe of the convex lens. In other words, by ſuch a glaſs, parallel rays are rendered divergent, converging rays have their convergence diminiſhed, and diverging rays have their divergence augmented in proportion to the concavity of the lens. Theſe glaſſes then exhibit objects ſmaller than they really are, for by cauſing the rays to diverge, or more properly by diminiſhing the convergence of the rays proceeding from the extreme points of the object, the viſual angle is rendered more acute, and the image painted on the retina is ſmaller than it would have been, had theſe rays not been intercepted in their natural progreſs; and by the divergence of the rays the object is repreſented with leſs clearneſs than it would otherwiſe have had, ſince from this cauſe a leſs quantity of light in fact enters the pupil of the eye. All concave lenſes have a negative or virtual focus, which is a point correſponding with the divergence of parallel rays incident on the ſurface of the lens.

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 two ſucceeding chapters the principles which have

have been juſt introduced to the notice of the reader will be further explained and elucidated; but as the application of the general doctrines of reflection and refraction to optical ſcience can only be underſtood upon mathematical principles, I have thought it proper to diſtinguiſh thoſe chapters by the ſcientific and technical words, catoptrics and dioptrics. In the mean time, the majority of readers will find ſufficient to ſatisfy their curioſity, and to afford them a general view of the nature and effects of this wonderful fluid in the preceding obſervations, and they may therefore proceed immediately to the ſeventh chapter, which treats of viſion and optical glaſſes.

CHAP. V.

OF THE PRINCIPLES OF CATOPTRICS.

Places of Images in plane Reflectors.—Why a Mirror only Half the Size of an Object exhibits a perfect Image of the Whole.—Places of Images made from Reflexion by ſpherical Surfaces.—Mode of determining the Foci of reflected Rays from ſpherical Surfaces.—Size and Proportions of Images in ſpherical Reflectors.—Phenomena of concave and convex Speculums explained.

BY the application of mathematical principles to the few ſimple facts with which experiment furniſhes us, concerning the reflexion and refraction of light, the phenomena of viſion have been reduced to a ſcience; and every particular which it becomes neceſſary to know either with reſpect to the ſimple effects of light on the human eye, or the uſe of glaſſes, may be calculated by certain rules with the minuteſt exactneſs. This complex ſcience is called OPTICS (or the ſcience of viſion) and it may be ſubdivided into two branches, called in ſcientific language *catoptrics* and *dioptrics*.

The firſt of theſe relates to the theory of reflex viſion, and ſupplies us with rules, principles, and modes of calculation, by which all the effects reſulting from the reflexion of light may be determined and explained; and of this it will be proper to treat, before we proceed to the other ſtill more important branch of optical ſcience.

The whole of the theory of catoptrics is founded upon a plain and ſimple principle, which has been already explained, viz. that the angle of reflexion is always equal to the angle of incidence. Thus let Q, Plate XI. (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.

The point Q, from which the rays diverge, is called the focus of diverging rays; and as, after reflexion, 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 to G D C, Q D M is equal to G D B, but G D B is equal to M D *q*; in the two triangles Q D M, M D *q*, there are two angles in the one equal to two angles in the other, and one ſide M D common to both, therefore Q M is equal to M *q*. The ſame may be proved alſo of the interſection of the lines H E *q* and Q M *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 Q R (fig. 2.) be a ſurface, from every point of which draw perpendiculars to the reflecting ſurface as before, and *q r* will be the image of Q R, or all the rays diverging from

QR will, after reflection, appear to have diverged from *q r*.

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 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 QR 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 reflexion. 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 QR, becauſe part of *q r* lies within the ſpace abovementioned, and to find the part of QR which is viſible by reflexion 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 reflexion will be ſeen in part of the reflecting ſurface only D B. All the reſt being ſuperfluons as to this object. Thus we can always find by what rays, and by what part of a reflecting ſurface, an object is ſeen. The limits of the ſpace in which an object muſt be placed to appear viſible by reflexion are, on theſe principles, eaſily 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 viſible at O by reflexion.

Thus, when we are placed before a looking-glaſs in a room, part of the room only is viſible; as we walk backwards and forwards other parts appear and diſappear in ſucceſſion, and ſome parts of the room are never ſeen in the glaſs.

When a perſon ſtands before a looking-glaſs of the ſame dimenſions with himſelf, his image appears to occupy the half of it, or, in other words, a looking-glaſs of half his dimenſions is capable of ſhewing him the whole of his figure. Let A B (fig. 3.) be an object placed before the reflecting ſurface *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 ſurface 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 C E, from the top of the object,

ject, cuts the right line *o b* E, at E. Let B *i* 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 *b* 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 of theſe reflected rays produced. But all the rays that flow from the object, and fall upon the mirror above *b*, 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 *b*, or below *i*, can be reflected to the eye at *o*; and the diſtance between *b* 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 *b* will be equal to *b o*, and A *b* is equal to *b* E. Therefore *b* E is equal to *o b*, and *o b* is one half of *o* E, and conſequently *i b* (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 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

Fig. 1.

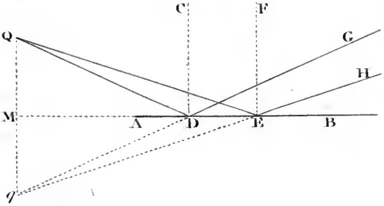


Fig. 2.

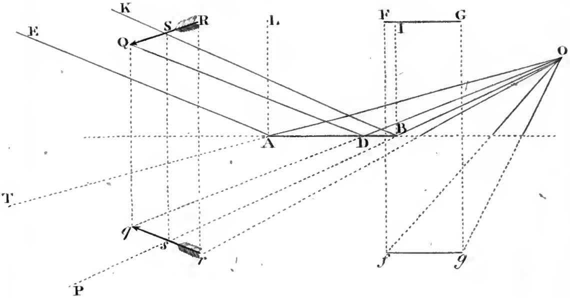
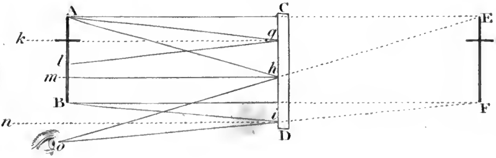


Fig 3



veral images of the ſame object appearing to be placed in a circle, whoſe center is the vertex of the acute angle, and radius the diſtance of the object from that vertex. Let M N O P, Plate XII. (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 reflexion 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 center, 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 reflexion 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 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 and the 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 reflexion, very nearly to the point T, and that point may be conſidered, and is conſidered, as the focus after reflexion 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 reflexion, 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.

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 reflexion, cut the parallel radius C *n* in *n*, biſecting the radius in that point; and, if a ray diverges from *n*, it will, after reflexion, 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 reflexion, 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

Fig. 4.

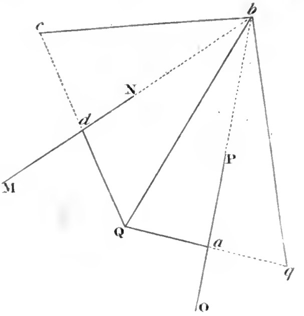


Fig. 5.

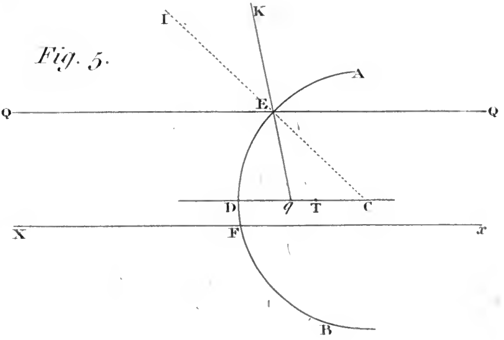
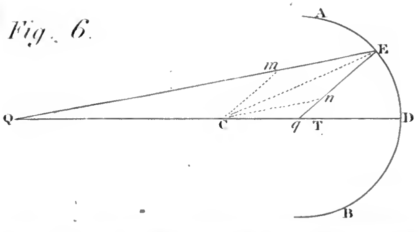


Fig. 6.



diſtance from the center of the ſurface will be a mean proportional between its diſtances from the foci of diverging and reflected rays.

In Plate XIII. 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 as 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* recedes 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 Q R (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 reflexion, 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 Q R, 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

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 than 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

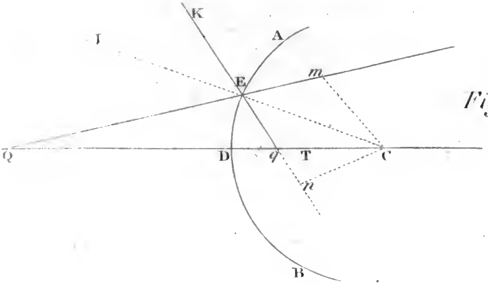


Fig. 7.

Fig. 8.

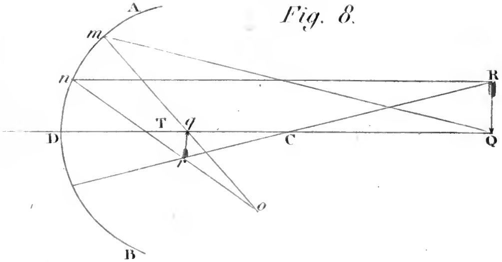
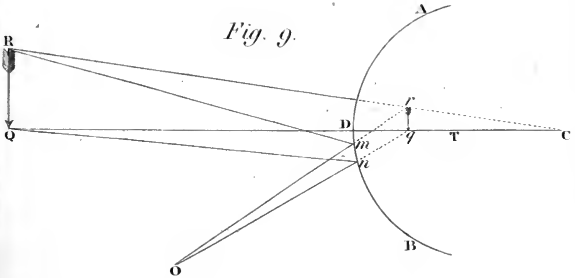


Fig. 9.



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, 9; 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 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.

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. VI.

OF THE PRINCIPLES OF DIOPTRICS.

Dioptrics relate to the Effects of Refraction.—In what Manner to find the actual Situation of an Object ſeen in a different Medium.—The apparent Situation of an Object ſeen through a Glaſs Window different from the real one.—The Effects of tranſparent Media with ſpherical Surfaces on the Rays of Light which are tranſmitted through them.—Rules for finding the Focus of Rays paſſing through ſuch Mediums.—Theory of Lenſes.—Plano-convex and plano-concave Lenſes.—Rules to find the Focus of a Lens.—Focus of diverging Rays intercepted to a Lens.—Focus of a Sphere.

THE word dioptrics is compounded of two Greek words, which mean to *ſee through*; and this branch of the ſcience of optics furniſhes us with rules and principles to determine with accuracy the effects of tranſparent mediums upon the rays of light, whatever may be the form of the ſurface through which the light is made to paſs. Thus, in an extenſive ſenſe, dioptrics would include the whole theory of optical glaſſes, and even of viſion itſelf. For the convenience of the ſtudent, however, I have thought it beſt to treat ſeparately of theſe ſubjects, and ſhall therefore in this chapter include only the general principles.

As the whole of dioptrics is founded on the laws of refraction, it will be neceſſary to recur to what was advanced on that ſubject in our fourth chapter, and to recollect that the angle of refraction is in a given ratio to the angle of incidence. Let H F for inſtance be a ray of light incident on the ſurface A B, (Plate XIV. 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 as 3 to 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 as 2 to 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 direction G L (in Fig. 10.) 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 is to the ſine of M F I as the ſine of N G K is to the 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 is to the radius as the ſine of incidence to the 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 in the direction *a b c*, as was explained in a preceding chapter.

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

diverged from Q, but from a point near to or farther 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* O : ſines 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 *mn*, and Q *m* O, R *n* O, are the directions nearly of the extreme rays by which the object is viſible.

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 A B C D (Fig. 15.) be a pane of glaſs, Q R an object ſeen through it, whoſe apparent place, found by the preceding rules, is xr, and let $Qmop$ repreſent the progreſs of one of the rays diverging from Q. Then, from what has been before obſerved, xp is parallel to Qm. Therefore $qm : mo :: Qq : Qx$, that is, when m is very near to E,

$$qE : EF :: Qq : Qx;$$
$$\text{or, } qE : Qq :: EF : Qx.$$

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

$$qE : Qq :: I : I - R,$$
$$\therefore EF : Qx :: I : I - R;$$

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 to 2; therefore I : I — R :: 3 : 1, and Qx will be therefore one third of EF; 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 ABC (Plate XV. Fig. 16.) be a glaſs priſm, QR an object ſeen through it by an obſerver at O. From Q draw QH perpendicular to the firſt ſurface AC, and let q be the focus of rays refracted by that ſurface; from q draw qE perpendicular on AB, the ſecond ſurface produced, if neceſſary, and ſuppoſing q then to be the

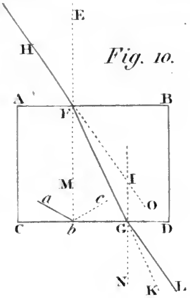


Fig. 10.

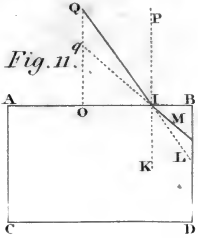


Fig. 11.

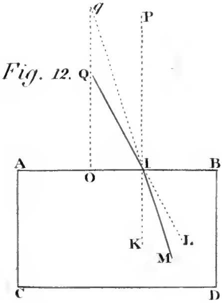


Fig. 12.

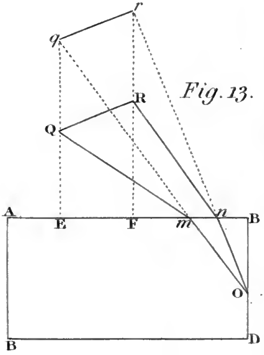


Fig. 13.

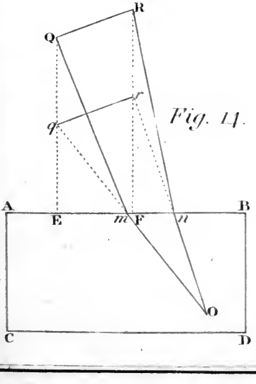


Fig. 14.

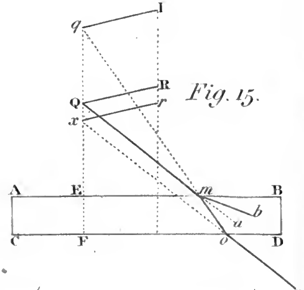


Fig. 15.

the focus of diverging rays falling on A B, let *x* be the focus of rays after refraction found by the proportion before laid down, or by joining H E, and drawing Q *x* 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 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 proceed 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 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 diverge after refraction. The focus of parallel rays thus found is called the principal focus, as formerly explained.

Let Q (Plate XVI. 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 Q I an incident ray, and ſuppoſe T to be the focus of rays parallel to C Q, incident on the concave ſurface A E B, 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 Q I 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 Q I *q*. Suppoſe now the ray *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

Fig. 16.

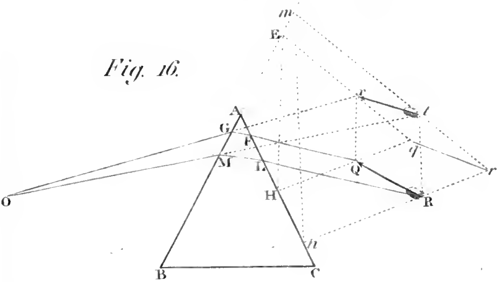


Fig. 17.

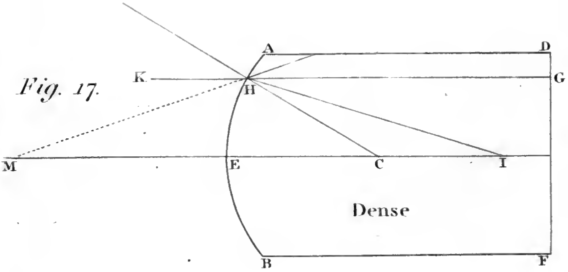
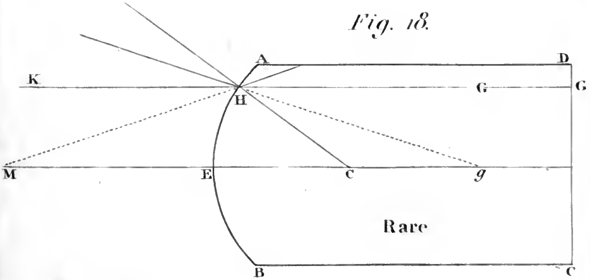


Fig. 18.



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, tq, and by making as Q T to T C, ſo C t to tq, 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 tq; 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 proportion, 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 ſide of the ſurface with Q and overtakes it at E.

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

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 a 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 diverging from any point, and intercepted by the convex ſurface of a rarer or concave ſurface of a denſer medium will by refraction, we have before ſeen, 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, 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 Q M (Plate XVII. 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 Q M. 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 Q M be at ſuch a diſtance from it, that its image ſhall be

Fig. 19.

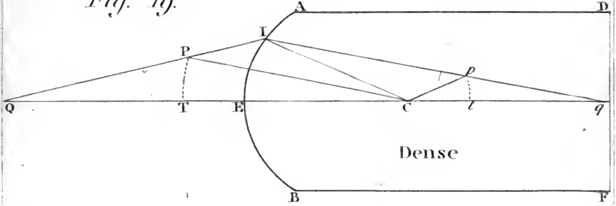


Fig. 20.

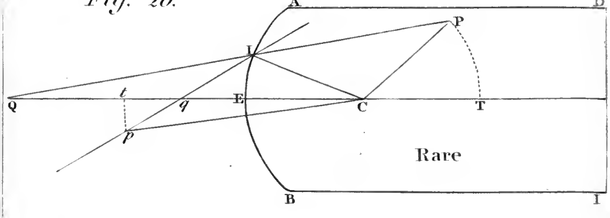
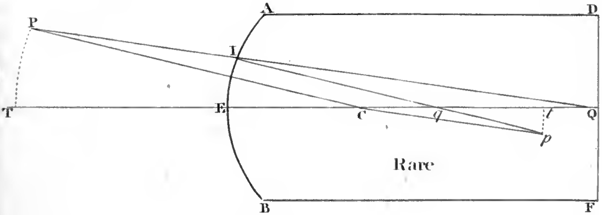


Fig. 21.



q m, and the place of the ſpectator O. He will ſee only part of the object correſponding to *n 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.

In the chapter which treated generally of refraction, the ſubject of LENSES was ſlightly and ſuperficially conſidered; the theory of theſe glaſſes remains now to be inveſtigated, and from their great importance in the ſcience of optics, it will be neceſſary to ſpeak of them ſomewhat in detail.

The different forms of lenſes have been already mentioned; but it is neceſſary to premiſe, 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 XVII. 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

Fig. 22.

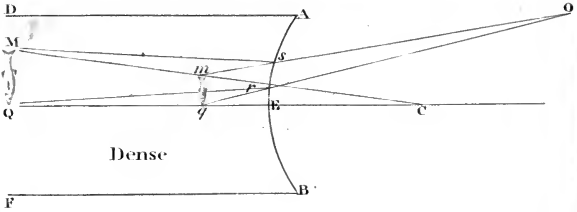


Fig. 23.

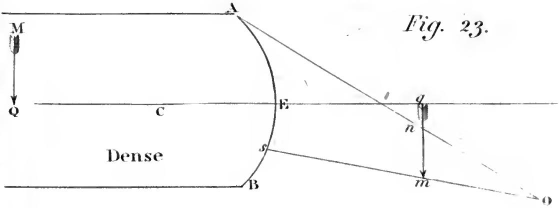


Fig. 24.

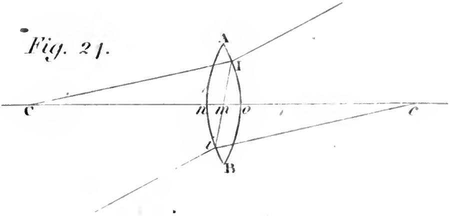
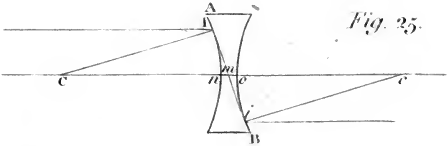


Fig. 25.



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 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 XVIII. 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 *m* in the ſpherical ſurface, for the point may be conſidered as in the tangent to the circle at *m*, 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* (Fig. 24, 25.) 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 XVIII. 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 center 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 XVIII. XIX. 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

rections 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 axis of the lens, the principal focus is in F. A double convex and plane convex lens, we have already ſeen, 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,

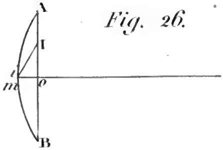


Fig. 26.

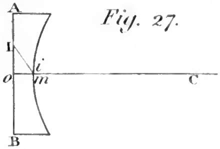


Fig. 27.

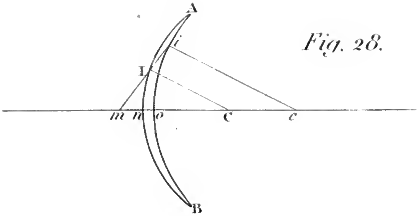


Fig. 28.

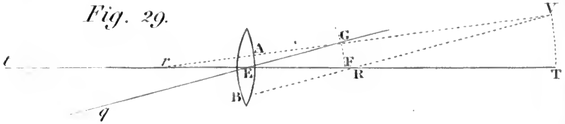


Fig. 29.

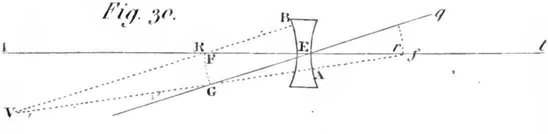


Fig. 30.

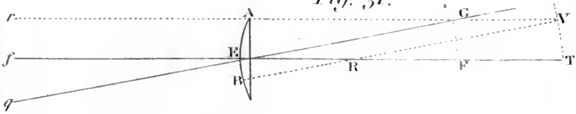


Fig. 31.

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 XIX. 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 conſidered 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*, ſimilar 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 ſimilar to that which we found before with ſingle ſurfaces.

The

The points Q and *q* will be on the oppoſite ſides of their reſpective foci. The greater Q F is, the leſs will be *qf*, and *vice verſa*; and the apparent places of objects viewed through theſe glaſſes will be found in the ſame manner as with ſingle ſurfaces. It will be ſufficient therefore only to refer the reader to Plates XIX. XX. Fig. 36, 37. which he will eaſily underſtand without farther explanation.

The principal focus of a ſphere is found with the ſame facility as that of a lens. Let M (Plate XX. Fig. 38.) be the principal focus of rays incident on the convex ſurface A O, then biſect M D in I, and I will be the principal focus of the ſphere. For let the ray G A be refracted by the convex ſurface to B, and at B by the concave ſurface to I, and let I B, G A produced meet each other in K. Now ſuppoſe that the ray A B within the ſphere emerged at both places A and B, then ſince the 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.

Fig. 32.

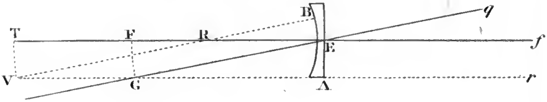


Fig. 33.

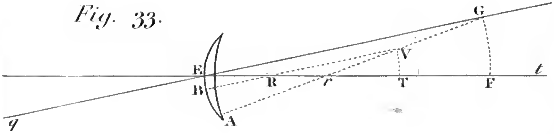


Fig. 34.

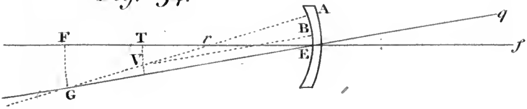


Fig. 35.

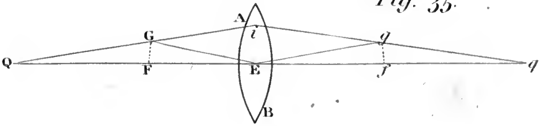
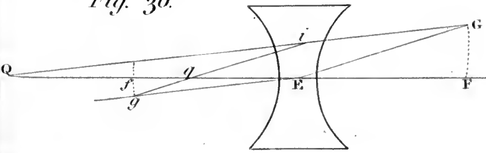


Fig. 36.



CHAP: VII.

OF VISION.

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.—Phenomena of Viſion.—Why the diſtant Parts of an horizontal Plain, and of the Sea, appear elevated.—Why a long Wall appears curved.—Why a high Tower appears falling to an Eye beneath.—Belt of Saturn.—Phenomena of Viſion as connected with Motion.—Why the Moon appears to move inſtead of the Clouds which paſs over its Face.—Why a Circle viewed obliquely appears oval.—How 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 XX. Fig. 39.) repreſent a ſection of the eye, M N being the pupil, A *qp* 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.

Now if the lens M N 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

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* Book IX. Chap. 41. Senſe of Sight.

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 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

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. In figure 40 let A B be an object viewed directly by the eye Q R. From each extremity draw the lines A N and B M, interſecting each other in the cryſtalline humour at I. Then draw the line I K in the direction in which the eye is ſuppoſed to look at the object. The angle A I B is then the optical or viſual angle, and the line I K is called the optical axis, becauſe it is the axis of the lens or cryſtalline humour continued to the object.

The apparent magnitude of objects then, depending thus on the angle under which they are ſeen, will evidently vary according to their diſtances. Thus different objects, as A B, C D, E F, the real magnitudes of which are very unequal, may be ſituated at ſuch diſtances from the eye as to have their apparent magnitudes all equal; for if they are ſituated at ſuch diſtances that the rays A N, B M, ſhall touch the extremities of each, they will then appear all under the ſame optical angle, and the diameter M N of each image on the retina will conſequently be equal.

In the ſame manner objects of equal magnitude, ſituated at unequal diſtances will appear unequal. For let A B and G H, two objects of equal ſize, be placed before the eye at different diſtances I K and I S; draw the lines G P and H O, croſſing each other in I; then O P, the image formed by the object G H on the retina, is evidently of a greater diameter than the image M N, which repreſents the object A B; in other words, the object G H will appear as large as an object of the diameter T V ſituated at the ſame place as the object A B.

Hence it follows, that objects ſituated at different diſtances, whoſe apparent magnitudes are equal, are to each other as their diſtances from the eye; and by the ſame rule, equal objects ſituated directly before the eye, have their apparent magnitudes in a reciprocal proportion to their diſtances.

This laſt propoſition muſt, however, be received with ſome allowance; for it is only applicable to very diſtant objects, and to thoſe where the ſenſe is not corrected by the judgment. For if the objects are near, we do not judge of their magnitude according to the viſual angle. Thus, if a man of ſix feet high is ſeen at the diſtance of ſix feet under the very ſame angle as a dwarf of only two feet high at the diſtance of two feet, ſtill the dwarf will not appear as large as the man, becauſe the ſenſe is corrected by the judgment.

In moſt caſes, however, where the diſtance is conſiderable the rule will be found accurate; and as it has its foundation in nature, moſt of the phenomena of viſion will be explained by having recourſe to the principles laid down in this chapter. If the eye is placed above a horizontal plain, the different parts of this plain will appear elevated in proportion to their diſtance, till at length they will appear upon a level with it. For in proportion as the different parts are more diſtant, the rays which proceed from them form angles with the optical axis I K more and more acute, and at length become almoſt parallel. This is the reaſon why,

Fig. 37.

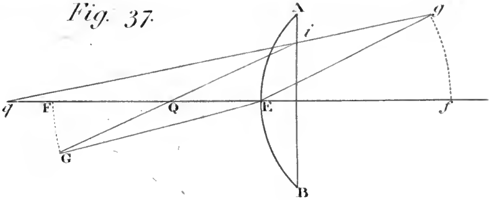


Fig. 38.

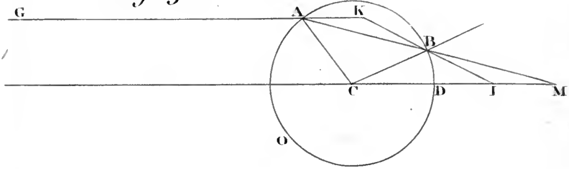


Fig. 39.

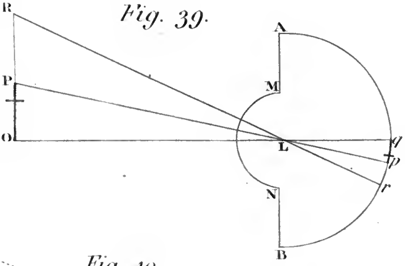
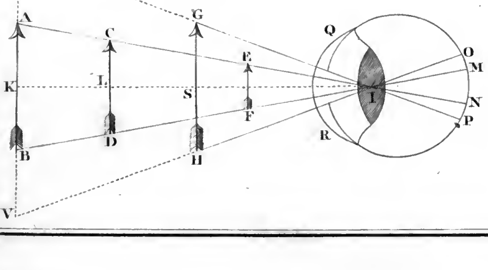


Fig. 40.



why, if we ſtand on the ſea-ſhore, thoſe parts of the ocean which are at a great diſtance appear elevated; for the globular form of the earth is not perceptible to the eye, and if it was, the apparent elevation of the ſea is far greater than the arch which a ſegment of the globe would form within any diſtance that our eyes are capable of reaching.

For the ſame reaſon, if a number of objects are placed on the ſame plain and at the ſame height below the eye, the more diſtant will appear taller than the others; and if the ſame objects are placed on a ſimilar plain above the eye, the more diſtant will appear the loweſt.

The diſtant parts of a long wall, for the ſame reaſon, appear to a perſon who ſtands near one end to curve or incline towards him. In the ſame manner the high wall of a lofty tower, ſeems to a ſpectator placed directly under it to bend over him, and threaten him with inſtant deſtruction. If any perſon inclined to make the experiment, will lie down on his back in a ſituation of this deſcription, at the diſtance of five or ſix feet from the wall of which he contemplates the tremendous height, he will immediately be made ſenſible of the phenomenon.

If the diſtance between two objects forms an inſenſible angle, the objects, though in reality at ſome diſtance from each other, will appear contiguous. This is aſſigned by ſome aſtronomers, as the reaſon why the ring or belt of Saturn appears as one maſs of light, while they contend that it is formed from a number of little ſtars or ſatellites ranged within a certain diſtance of each other.

If the eye is carried along, as in a boat, without being ſenſible of its own motion, the objects which are ſtationary on each ſide, will appear to move in a contrary direction. Thus we attribute to the ſun and the other heavenly bodies, a diurnal motion, which only affects the earth which we inhabit.

If two or three objects at a conſiderable diſtance, and on which the eye of the ſpectator is fixed, move with equal velocity paſt a third object which is at reſt, the moving objects will appear to be actually at reſt, and that which is really ſtationary will appear in motion. Thus the clouds which paſs over the face of the moon appear at reſt, while the moon itſelf appears to proceed rapidly along in an oppoſite direction. This happens, becauſe the eye which is fixed upon the clouds follows their motion mechanically, and therefore the moon appears to move and not the clouds, as in the boat we do not perceive its motion, but conceive the banks are retiring behind us.

If the center of the pupil, that is, the optic axis is directed along the ſurface of any ſlender object in a perfectly right line, this line will appear only a point, becauſe, in fact, the extremities only are viſible.

An extended and diſtant arch, viewed by an eye which is exactly in the ſame line, will appear as a plane ſurface, becauſe all the parts appearing equally diſtant, the curvature will not be perceived.

If a circle is viewed obliquely it will appear an oval, becauſe the diameter which is perpendicular to the eye is ſhortened; in other words, the rays which proceed from the extremities form an angle ſo much the more acute as the obliquity is greater; on the contrary, the diameter which is parallel to the eye is apparently extended.

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

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is an angle q L 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 of a degree; and each perſon may diſcover the ſtrength of his ſight by taking an object of a determinate length, and removing it to ſuch a diſtance that it ſhall juſt ceaſe to be viſible, or appear only as a point.

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. The ſimpleſt contrivance, where the object is either too minute or too diſtant, is to interpoſe between the eye and the object a glaſs or lens, which by its magnifying power, or, in ſtill clearer terms, its power of converging the rays of light, ſhall enlarge, or render more obtuſe the angle under which it is preſented to the naked eye, and which muſt of courſe proportionably enlarge the image depicted on the retina. To find by what ſort of glaſs or lens an object is to be ſeen at any diſtance,

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* 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 $\frac{1}{1200}$ part of an inch broad. And all ſmaller objects are inviſible to the naked eye.

we muſt take into conſideration the diſtance of the object, and the diſtance of diſtinct viſion, from which it will be eaſy to find a lens of ſuch a focal length as will make the object appear at the diſtance required *.

By want of attention in the choice of glaſſes, a defect in ſight may be conſiderably increaſed, for the eye may be ſtrained to an accommodation with the glaſs. Short-ſighted perſons, as they advance in years, are often found to improve in ſight; long-ſighted perſons, on the contrary, find their ſight impaired by age. For the convexity in the pupil of both diminiſhes with years †; in one caſe it was too great, and conſequently the diminution was beneficial; in the other caſe it was already too ſmall, and the diminution muſt be conſequently prejudicial.

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* For in Plate XXI. Fig. 41, 42, the triangles QAq, Egq, are ſimilar; 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 glaſs is equal to the rectangle under the diſtances of diſtinct viſion, and the given object divided by the difference of theſe diſtances.

If in the caſe of ſhort-ſighted perſons, the object is at ſuch a diſtance that the rays coming from it to the eye may be conſidered as parallel, QE and Qq may be conſidered as equal without any material error, and the focal length of the glaſs will then be equal to the diſtance of diſtinct viſion.

† This is the generally received opinion, but from ſome obſervations lately communicated to the world in the Philoſophical Tranſactions, by Dr. Hoſack, there is reaſon to believe, that the convexity and concavity are not changed, as was generally imagined, but that the muſcles of the eye grow weaker, like other muſcles, by age, and conſequently are not able, as in early life, to vary the diſtance between the retina and anterior ſurface of the eye, ſo as to make it correſpond to the diſtance of the object. See Book IX. Chap. 41.

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With a ſingle glaſs the defects in ſight, with reſpect to many objects either too near or at too great a diſtance, for the perſons labouring under them, are remedied; but there are caſes where the object is ſo far diſtant or ſo minute, that though its outline may reach the eye, its parts muſt ſtill, even with the aid of a ſingle lens, be indiſtinctly perceived. The art of man has diſcovered a remedy, in a great degree, to this imperfection, and by means of a combination of glaſſes has opened a wide field for his reſearches into the wonders of nature; he can now trace the limbs of an inſect inviſible to the naked eye, or he can make the celeſtial objects appear to him as if their diſtance had been on a ſudden diminiſhed by many millions of miles.

CHAP. VIII.

OF TELESCOPES AND OTHER OPTICAL INSTRUMENTS.

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

LET QP (Plate XXI. 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 $q\,\mathrm{F}\,p$ to $q\,\mathrm{E}\,p$, that is, as $q\,\mathrm{E}$ to $q\,\mathrm{F}$, 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 aſtro-

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* ' When the diſtance of the object is very conſiderable, the effects may all be referred to the ſame diſtance, and a teleſcope may be ſaid to enlarge an object juſt as many times as the angle under which it repreſents it is greater than that under which it appears to the naked eye. Thus the moon appears to the naked eye under an angle of about half a degree; conſequently a teleſcope magnifies 100 times, if it repreſents the moon under an angle of 50 degrees; if it magnified 200 times, it would exhibit the moon under an angle of 100 degrees; and the moon would appear to occupy more than half the viſible heavens, of which the whole extent is only 180 degrees.

' It is a common expreſſion, that teleſcopes bring objects nearer; but this expreſſion is equivocal, admitting of two different ſignifications. The one is, that, looking through a teleſcope, we eſtimate an object to be as much nearer to us as it is magnified by the teleſcope. But I have already ſhewn, that we can form no certain eſtimate of the diſtance of an object but by the judgment, and that our judgment deceives us when the objects are beyond a certain diſtance; and in the preſent inſtance, loſing all thoſe ſubjects of compariſon on which it is founded, will deceive us more. The other meaning applied to the expreſſion is, that the teleſcope repreſents the objects as large as they would appear if we were ſo much nearer to them: this latter meaning is more conformable to the truth than the preceding, for the nearer we approach to an object the larger is the viſual angle. When you look, however, at a well-known object, as a man, at a great diſtance, and he is ſeen under a larger angle, we are led to think him ſo much nearer, when he would really appear under a greater angle; but with reſpect to objects leſs known, as the ſun and moon, there can be no eſtimation of diſtance.

' One principal end of teleſcopes is to enlarge or multiply the angle under which objects appear to the naked eye, and they are eſtimated according to this effect, and are ſaid to magnify five, ten, or any other number of times, according to the nature and conſtruction of the teleſcope.'—*Adams's Lect.* vol. ii. p. 483.

nomers, 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

Fig. 41.

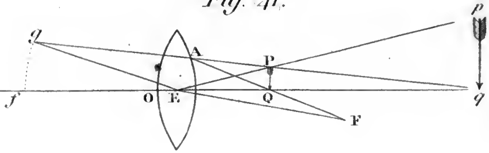


Fig. 42.

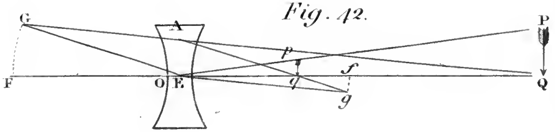


Fig. 43.

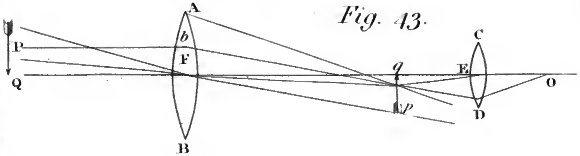


Fig. 44.

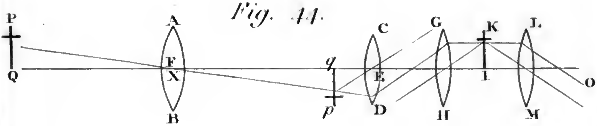
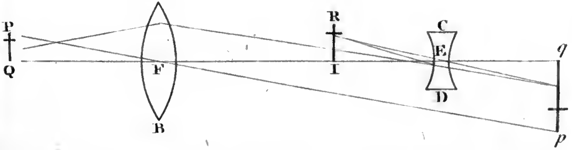


Fig. 45.



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 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.) *q p* being the image of Q P, by placing a double concave lens between this image and the object-glaſs, the rays converging to *p* appear to diverge from R, and I R, the image ſeen by the eye at Q, is made erect. In this caſe, the nearer the eye is placed to the glaſs, and the greater the pupil, the more 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 our glaſſes to

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* 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 ſingle microſcopes, and the latter compound or double. The former is conſtructed in this manner: ſuppoſe a ſmall object ſituated 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 intermediate points of the object will be formed into a picture, which will be as much larger than the object in proportion as the diſtance of the ſcreen exceeds that of the image from the lens.

diſcover the magnifying power, it is neceſſary only to compare together the angles under which the object is ſeen through the eye-glaſs, and that under which it would have been ſeen by the naked eye.

Inſtead of lenſes only, for reaſons hereafter to be mentioned, a combination has been formed of reflecting ſurfaces and lenſes, and from the names of the inventors, thoſe of the greateſt uſe are now called the Newtonian, Gregorian *, and Herſchelian teleſcopes. The reflecting teleſcope on the Gregorian principle, which is the moſt common, as it is found to be the moſt convenient, is conſtructed in the following manner.

At the bottom of the great tube (Plate XXII. fig. 46.) T T T T is placed a large concave mirror D U V F, whoſe principal focus is at *m*, and in the middle of this mirror is a round hole P, oppoſite to which is placed the ſmall mirror L, concave toward the great one, and ſo fixed to a ſtrong wire M, that it may be removed further from the great mirror, or nearer to it, by means of a long ſcrew in the inſide of the tube, keeping its axis ſtill in the ſame line 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

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* The difference between the Newtonian and Gregorian teleſcope is, that in the former the ſpectator looks in at the ſide through an aperture upon a plane mirror, by which the rays reflected from the concave mirror are reflected to the eye glaſs, whereas in the latter, the reader will ſee that he looks through the common eye-glaſs, which is in general more convenient, and therefore that is the teleſcope which is now in the moſt univerſal repute.

two rays of a pencil flowing from each extremity of the object into the great tube, and trace their progreſs through all their reflexions 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 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

mity 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 reflexion 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,

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 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 the notice of 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 ſlid-

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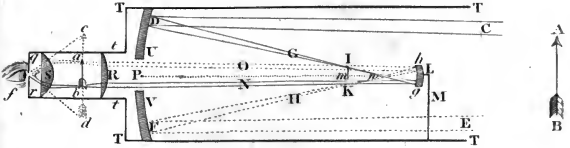
* Ferguſon's Lectures, p. 235.

† See Phil. Tranſ. 1784.

Fig. 46.



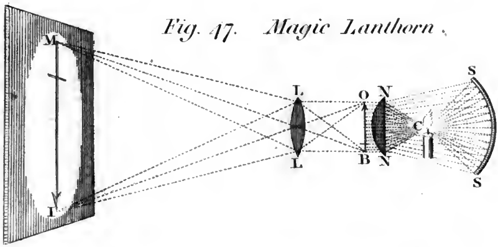
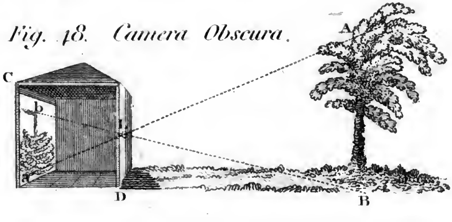


Fig. 47. Magic Lanthorn.

Fig. 48. Camera Obscura.



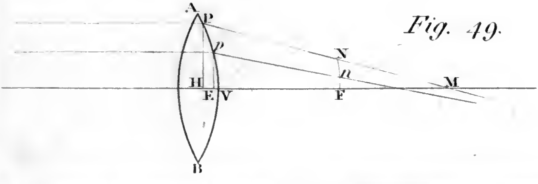


Fig. 49.

ing piece in which the glaſs is ſet or fixed. This illumination is ſtill more increaſed by the reflexion 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 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 is 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* *.

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

CHAP. IX.

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 XXII. 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 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

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* This ſubject has been partly anticipated in the 1ſt and 4th chapters of this book, in which it was neceſſary to give a ſuperficial account of the diſcoveries concerning light, and of the nature of refraction. 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.

ple proportion, but the triplicate of the ſemi-aperture *. Thus, if P V and *p* V repreſent the ſame glaſs with different apertures P H, *p* E, the latitudinal

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* Let K *a*, L *b* (Plate XXV. 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 ∴ increment of the angle of incidence : increment of refraction :: $aEb : aEb + amb$.

∴ $aEb : amb$ :: 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.

∴ $aEb : amb :: OG : HO$.

With *m* as center, and *m b* radius, deſcribe the arc *b d*, then $aEb : amb :: \frac{ab}{Eb} : \frac{bd}{bm}$.

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

Hence $bM : bH :: OG : HO$, and G *m* joining the points G and *m* is parellel to the incident rays, and conſequently by 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 *m g* from the axis C F, varies as the cube of the ſemi-aperture of the ſpherical ſurface.

nal 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, conſidering the errors to which they were thus expoſed by the ſpherical form of their

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 *m g* 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 *m g*, and conſequently if the rays of the ſun are refracted by a concave ſurface, and received by an opake body perpendicular to the axis at the diſtance C *g*, a circle of light will be 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 *m i*, they will, at a greater diſtance from the ſurface, paſs through a much ſmaller circle *n p*, 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.

glaſſes,

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 whoſe various combinations all the beautiful colours in nature originate.

The experiment on which this diſcovery is founded is thus deſcribed by Newton himſelf.

'In a very dark chamber, at a round hole F (Plate XXIII. Fig. 50.) about one-third of an inch broad, made in the ſhut of a window, I placed a glaſs priſm A B C, whereby the beam of the ſun's light, S F, which came in at that hole, might be refracted upwards, toward the oppoſite wall of the chamber, and there form a coloured image of the ſun, repreſented at P T. The axis of the priſm (that is, the line paſſing through the middle of the priſm, 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 priſm ſlowly, and ſaw the refracted light on the wall, or coloured image of the ſun, firſt to deſcend, and then to aſcend. Between the deſcent and aſcent, when the image ſeemed ſtationary, I ſtopped the priſm and fixed it in that poſture.

'Then I let the refracted light fall perpendicularly upon a ſheet of white paper, M N, placed at the oppoſite wall of the chamber, and obſerved the figure and dimenſions of the ſolar image, P T, formed on the paper by that light. This image was oblong, and not oval, but terminated by two rectilinear and parallel ſides and two ſemicircular ends. On its ſides it was bounded pretty diſtinctly; but on its ends very confuſedly and indiſtinctly, the light there decaying and vaniſhing by degrees. At the diſtance of $18\frac{1}{2}$ feet from the priſm, the breadth of the image was about $2\frac{1}{8}$ inches, but its length was about $10\frac{1}{4}$ 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 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 reflexion or tranſmiſſion of the various combinations of the colour-making rays *, If the rays alſo of light were not thus compounded, every

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* 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 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 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 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 realiz-

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vironed 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 reflexion. 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 reflexion; 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.

ing, 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 b*, *g b*, 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

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 *oo*, *oo*: 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 diverging 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 violet 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

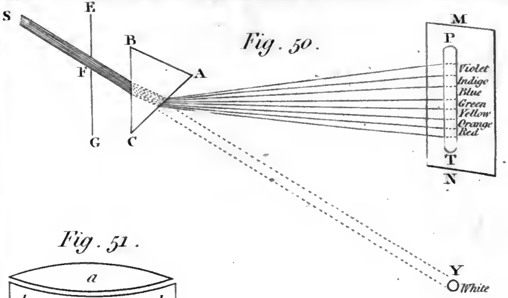


Fig. 50.

Fig. 51.

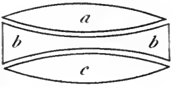
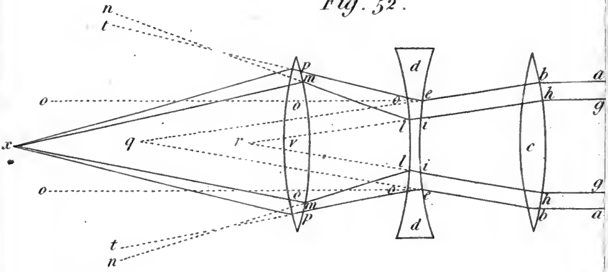


Fig. 52.



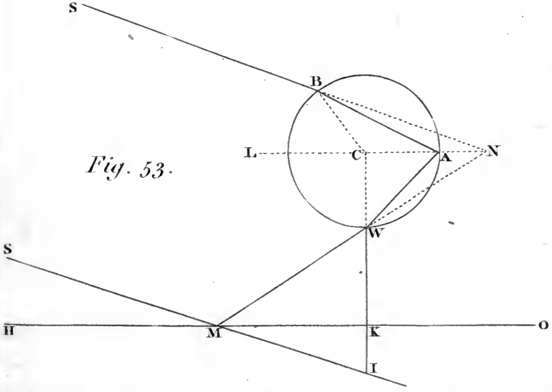


Fig. 53.

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, 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 compound 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 achromatic 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 de-

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

parted 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 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 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 perfectly black, while the light tranſmitted through the uncoated parts of the phials

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

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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, 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

flected 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 ſubſtratum 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 different 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 the powder exhibits. If oil, inſtead of air, intercedes the interſtices of powdered ſubſtances, in proportion as it approaches to the denſity of the ſubſtances themſelves, and as it exceeds air in this reſpect, it renders the colour proportionably darker. "Thus when indigo, and other tranſparent paints, are united with oil, the air is expelled from their interſtices, and the oil which is admitted in its ſtead, from the nearneſs of its denſity to that of the powder, reflects no ſenſible light, ſo that the maſs, which conſiſts of ſuch uniformly denſe media, is black." "When ſmooth ſurfaces of dark-coloured marble or ſlate, or any other poliſhed ſubſtance, are ſcratched, the air enters into the interſtices which are opened by this operation, and according to the exceſs of its rarity over that of the maſſes which it intercedes, it reflects a whiter or lighter coloured hue.

By poliſhing the ſurface alſo, the air is removed from them, and the dark hue is reſtored."

From theſe experiments he concludes, " that vegetable, animal, and mineral coloured matter is tranſparent; that it does not reflect colours, but only exhibits them by tranſmiſſion; that opake coloured bodies conſiſt of tranſparent matter covering opake white particles, and tranſmitting the light which is reflected from them."

With reſpect to the ſemi-pellucid ſubſtances, ſuch as the ſolution of lignum nephriticum, &c. which appear of one colour by incident and another by tranſmitted light, he ſays, " they conſiſt of pellucid media, through which white or colourleſs opake 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. X.

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 lour 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 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 earthquake, while the optician contemplates them merely

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 all or ſome of 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 A W (Plate XXIII. 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 A 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 A, 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 (Plate XXIV. Fig. 54.) It is evident that the angle C E P is leſs than the angle B E P, and that the angle A E P 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

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, 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 A, 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 A, then by reflection from A 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 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 par-

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* 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. B C L = C B N + C N B, and alſo B C L = C A B + C B A = 2. C B A.

$\therefore$ C B N + C N E = 2. C B O.

$\therefore$ C N B = 2. C B A — C B N.

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*. C B A — C B N.

This angle C N B, if the angle of incidence increaſes from nothing, firſt increaſes and then decreaſes, therefore *m* C B A — C B N will in ſome places be a maximum; that is, where *m* times the fluxion of C B A, is equal to the fluxion of C B N.

Let C B A = A and C B N = B.

$\therefore \dot{A} : \dot{B} :: 1 : m$

and radius being equal to unity

$$\dot{A} : \dot{B} :: \frac{\dot{S}\,A}{\text{coſ. }A} : \frac{\dot{S}\,B}{\text{coſ. }B} :: \frac{S\,A}{\text{coſ. }A} : \frac{S\,B}{\text{coſ. }B}$$

$$\text{but tang. }A : \text{tang. }B :: \frac{S.\,A}{\text{coſ. }A} : \frac{S.\,B}{\text{coſ. }B.}$$

$\therefore$ tang. A : tang. B :: 1 : *m*

Hence

a particular colour. When the plane H M W A is perpendicular to the horizon, the line M W is directed to the vertex of the bow, and W K is its altitude.

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 $x = \text{coſ. of A.}$

$y = \text{coſ. of B.}$

$$\therefore \sqrt{1-x^2} = \text{ſine A, and } \frac{\sqrt{1-x^2}}{x} = \text{Tan. A.}$$

$$\sqrt{1-y^2} = \text{ſine B, } \frac{\sqrt{1-y^2}}{y} = \text{Tan. B}$$

$$1-x^2 : 1-y^2 :: R^2 : I^2$$

$$\frac{1-x^2}{x^2} : \frac{1-y^2}{y^2} :: 1 : m^2.$$

$$\therefore x^2 : y^2 :: m^2 R^2 : I^2$$

$$\therefore x^2 = \frac{m^2 R^2 y^2}{I^2}$$

$$1-x^2 = \frac{I^2 - m^2 R^2 y^2}{I^2}$$

$$\therefore \frac{I^2 - m^2 R^2 y^2}{I^2} : 1-y^2 :: R^2 : I^2$$

$$I^2 - m^2 R^2 y^2 = R^2 - R^2 y^2$$

$$I^2 - R^2 = m^2 R^2 y^2 - R^2 y^2$$

$$\therefore 1 : y :: R \times \sqrt{m^2 - 1} : \sqrt{I^2 - R^2}$$

Hence the co-ſine 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 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.

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 A, 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 between 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.

Fig. 54.

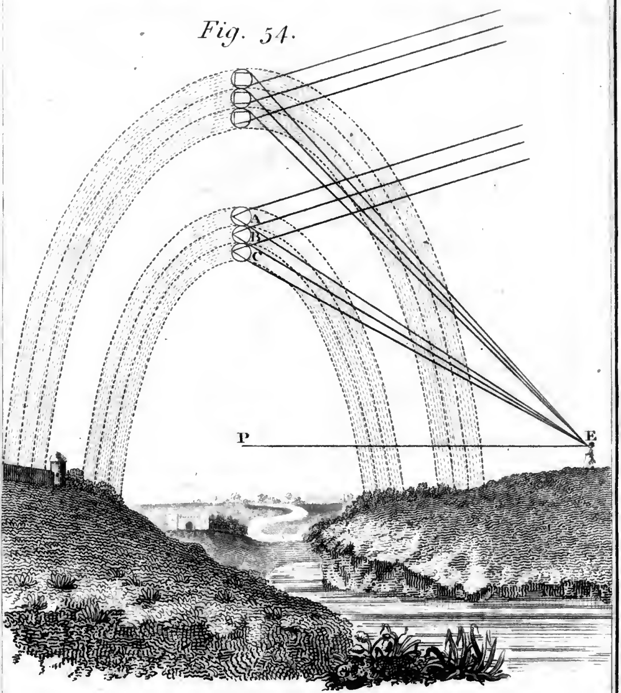
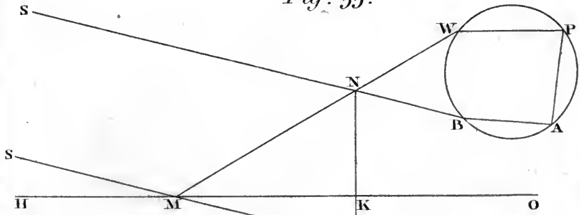


Fig. 55.



In the ſame manner innumerable bows might be formed 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 will be produced 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 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 account 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 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, 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,

ple, 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 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 Cordileras, 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.

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* Prieſtley's Hiſt. of Opt. p. 597.

Similar

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 appearances 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

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* Prieſtley's Hiſt. Opt. p. 600.

† Ibid, p. 613.

‡ Ibid. p. 614.

large white circle, parallel to the horizon, 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 Plate XXV. 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 entirely 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, 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

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 Churchill, 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 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

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* Prieſtley's Hiſt. Opt. p. 614 to 617.

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 detailed. 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 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

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* Prieſtley's Hiſt. Opt. p. 617.

† On this account, diſtant mountains covered with ſnow (which it is well known reflect all the rays of the ſun) appear, when the air

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 clouds, they reflect the white light of the ſun, and appear white, whenever its incident rays fall on them entire and undivided; and as the reflecting particles are not equally diffuſed through every part of the pellucid air, of which the atmoſphere principally conſiſts, it frequently happens that large tracts of air are only furniſhed with ſuch a portion as qualify them to reflect a blue colour, while others are ſo denſely ſtored as to form clouds.

Of the red and vivid colour of the morning and evening clouds Mr. Melville has ſuggeſted a cauſe upon ſimilar principles, which we muſt at leaſt allow is ingenious and probable. He ſuppoſes, as well as Mr. Delaval, that a ſeparation of the rays is made in paſſing through the horizontal atmoſphere, and that the clouds reflect and tranſmit the ſun's light, as any half tranſparent colourleſs body would do; for as the atmoſphere reflects a greater quantity of blue and violet rays

air is thick, and [the ſun nearly oppoſite them, of a warmer colour than they otherwiſe would, and more approaching to yellow or orange.

rays than of the reſt, the ſun's light tranſmitted through it inclines towards yellow, orange, or red, eſpecially when it paſſes through a long tract of air; and in this manner the ſun's horizontal light is tinctured with a deep orange, and even red, and the colour becomes ſtill deeper after ſun-ſet; hence he concludes, that the clouds, according to their different altitudes, may aſſume all the variety of colours at ſun-riſing and ſetting, by barely reflecting the ſun's incident light as they receive it.

The green colour of the ſea may alſo be accounted for in the ſame manner. Sir Iſaac Newton, and others, have ſuppoſed 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 aud 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

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* Newton's Opt. l. 1. Part 2d.

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 greater reflective power than thoſe which are diſperſed through the atmoſphere. Inſtead, therefore, of reflecting a delicate blue, ſuch as that of the ſky, the ſea 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 ſome of the leſs refrangible, as the yellow or orange.

With reſpect to the phenomena remarked by Dr. Halley, it is eaſy to conceive that the light, when ſtripped of all the more refrangible rays, ſhould produce a roſe colour, ſuch as that he obſerved on the upper part of his hand; on the contrary, that which illuminated the lower part of his hand conſiſted partly of rays reflected from the ground, and partly of thoſe which were reflected from the internal parts of the ſea water, which, we have ſeen, are chiefly blue and violet; and the mixture of theſe produced the greeniſh tinge which the Doctor remarked *, and which common experience ſhews is the predominant colour of the ocean.

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* Delaval on the cauſes of colours in opake bodies, vol. ii. Manch. Mem.

CHAP. XI.

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 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

Fig. 56.

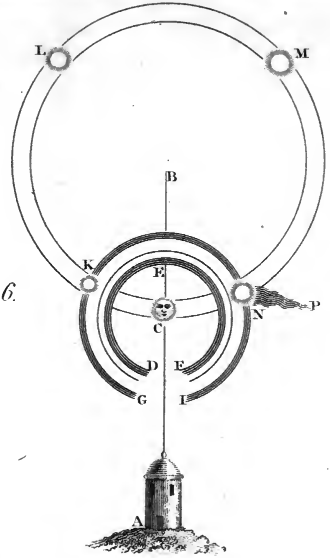


Fig. 57.

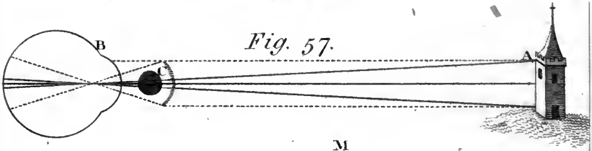
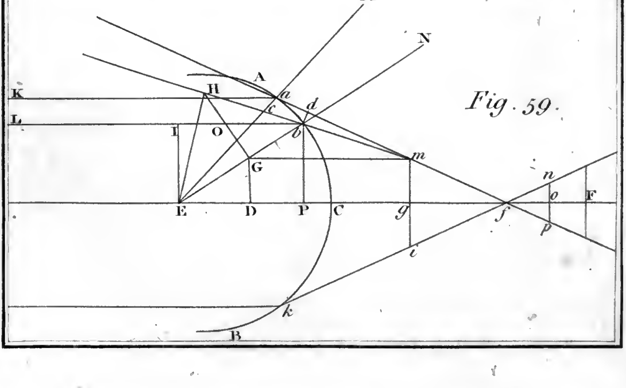


Fig. 59.



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 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

quently 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 IV.

OF ELECTRICITY.

CHAP. I.

HISTORY OF DISCOVERIES RELATIVE TO ELECTRICITY.

Origin of the Name.—How far Electricity was known to the Antients.—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 almoſt 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 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.

riments. 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, that 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 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

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, 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

as to intercept the electric power, 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 expement 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 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 electic 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 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,

trified, 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 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 the Leyden phial is well known; and this was ſoon followed by another

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 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 electic 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,

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 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.

It was afterwards diſcovered by Mr. Canton, 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.

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 branch of ſcience, 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 electrified body, ſince if we place either our hands or face before an excited tube of glaſs, or before an inſulated conductor which is electrified, we ſhall perceive emanations ſenſible to the touch, and if we approach nearer, we ſhall feel it diſtinctly, and hear a weak noiſe; in the dark we perceive ſparks of vivid light, eſpecially from angular points; we ſee emitted pencils of rays, or ſmall flaſhes of divergent flame; it is certain, therefore, that ſome ſubtile matter put in motion is alone capable of making theſe impreſſions upon our ſenſes; and we may conclude, that every electrified body is encompaſſed by ſome matter in motion, which is, without doubt, the immediate cauſe 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 philoſophy, that of experiment, fact, and obſervation. There is, however, in man, a curioſity that prompts us to look beyond effects, and a diſpoſition that leads us to theorize, even on the moſt difficult ſubjects. 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 ſuffers no ſenſible diminution. It depends not on any property inherent in the air of the atmoſphere, for three obvious reaſons; firſt, becauſe electrical phenomena may be produced in a ſpace from which the air has been moſt carefully exhauſted. Secondly, Becauſe the electrical matter has qualities which are not inherent in air; it penetrates certain bodies impervious to air, ſuch as metals; it has a ſenſible odour; it appears itſelf inflamed; it is capable of inflaming other bodies, and of melting metals; effects which air cannot produce. Thirdly, It tranſmits its motions with conſiderably more rapidity than that of ſound, which is a motion of the air the moſt rapid that we are acquainted with.

It is generally agreed, that the electric matter has a ſtrong analogy with the matter of heat and light. It appears indeed, that nature, who is ſo very œconomical in the production of principles, whilſt ſhe multiplies their properties ſo liberally, has in no caſe eſtabliſhed two cauſes 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 thoſe of the matter of heat and light, the more ſhall we diſcover of this analogy between them, and the more probable will it appear, that fire, light, and electricity depend upon the ſame principle, and that they are only three different effects from the ſame matter or eſſence.

1ſt. Of all the means neceſſary to excite the matter of heat, there is none more efficacious than that which is moſt neceſſary to produce electricity, namely, friction. 2dly. As fire, or caloric, extends itſelf with more facility in metals and humid bodies than in any other ſpecies of bodies, ſo metals and water are conductors of electricity in the ſame manner as they are of heat, and, in general, the ſame conductors are found equally good for both. 3dly. Fire, or caloric, is the moſt elaſtic of all bodies, and is conſidered by moſt philoſophers as the principal cauſe of that repulſion which takes place between the particles of bodies, of which the ſtrongeſt inſtance has already been given in explaining the cauſe of fluidity; and to a ſimilar cauſe the electric repulſion may be referred. 4thly. The pulſe and perſpiration of animals are increaſed 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 ſpirit of wine by the electric ſpark; inflammable air is ſet on fire by the ſame means in the common electrical piſtol; and even gunpowder may be exploded by a ſpark from a powerful conductor. 6thly. Metals are melted by electricity,

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* Count Rumford's experiments, Phil. Tranſ. vol. lxxvi.

city, and moſt inflammable ſubſtances are affected by it as by common fire, but in a weaker degree *. 7thly. The light emitted by the 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,

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* Mr. Kinnerſley made a large caſe of bottles explode at once through a fine iron wire; the wire at firſt appeared red hot, and then fell into drops, which burned themſelves into the table and floor, and cooled in a ſpherical form like ſmall ſhot. Artificial lightning, from a caſe of about thirty-five bottles, will entirely deſtroy braſs wire of one part in three hundred and thirty of an inch. Metals may alſo be revived by the electric ſhock; and Sig. Beccaria melted borax and glaſs by it. Prieſtley's Hiſt. Elect. vi. 341—343. Seeds of clubmoſs (lycopodium) were fired by it; alſo aurum fulminans, ib. 343.

† Memoires de l'Acad. des Sci. 1733, p. 247.

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.

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 baſis of the electric matter is radically the ſame with the matter of heat or light, it muſt alſo be admitted, that it re-

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* Count Rumford's experiments above quoted.

† Ibid.

tains 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 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 if 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 ſpread; 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, 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 homogeneous 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 by 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 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

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 is open or cloſed at the extremities; yet it is neceſſary that the air within ſhould be in the ſame ſtate as that without; for this reaſon the tube ſhould at leaſt be open at one end; but care muſt be taken leſt dirt ſhould be admitted into the inſide, for that would conſiderably impede its effects. If, notwithſtanding theſe precautions, the tube receives either dirt or moiſture, ſome dry and fine ſand ſhould be introduced into the inſide, and it ſhould be afterwards cleaned out with fine dry cotton.

When it is intended to electrify a tube, it is only neceſſary 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 ſufficiently charged with the electric fluid. This friction may be performed with the naked hand when it is dry and clean, otherwiſe 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 ſubſtances are preſented to it, they will be firſt attracted towards it and immediately afterwards repelled.

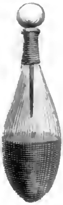
The electric fluid may be excited in nearly a ſimilar manner, by rubbing a ſtick of ſulphur or ſealing wax.

Theſe tubes being but ſmall, the electric fluid produced by theſe means is but feeble in its effects. We have ſeen that a method was contrived to turn a globe of glaſs upon its axis, by means of a machine with a winch or multiplying wheel; this method 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 RO (ſee Plate XXVI. Fig. 1.) ſhould be at leaſt four feet in diameter, and be turned round in a ſtrong and ſolid frame H I C D. 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

Fig. 3.



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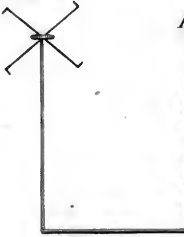
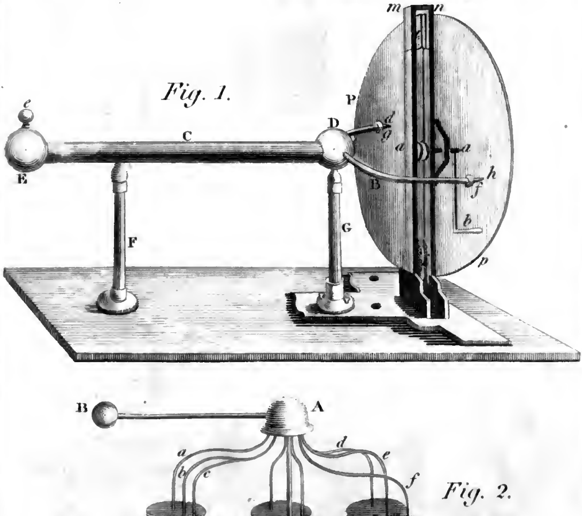


Fig. 5.

Fig. 1.



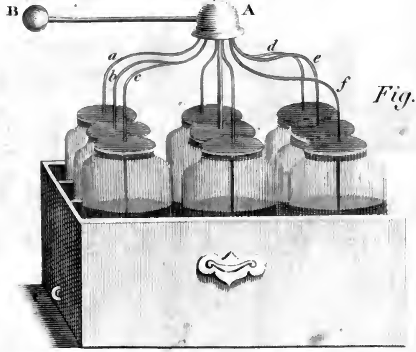
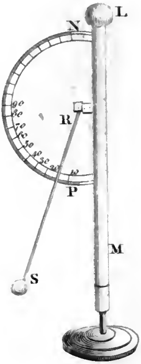


Fig. 2.

Fig. 3.



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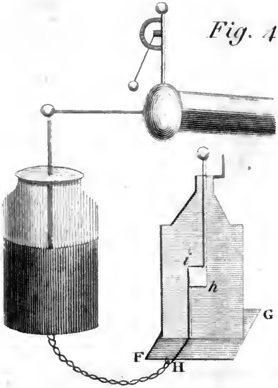

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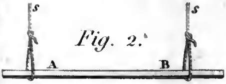
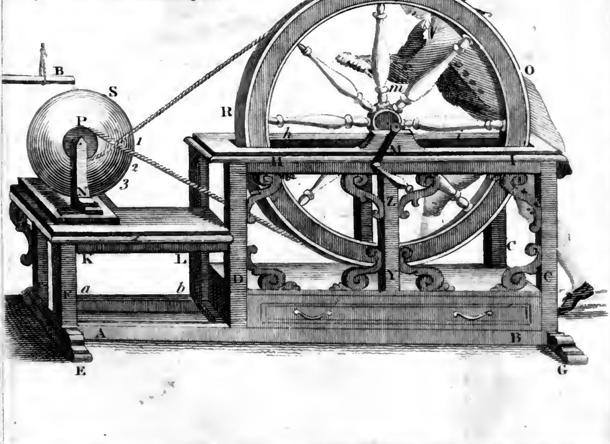


Fig. 1.



and dry. A bar of iron (A B, Fig. 2.) inſulated with the cords of ſilk *s*, *s*, is placed over 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 XXVII. 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 plate 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.

This machine is, however, feeble in its operations, compared with thoſe conſtructed with globes or cylinders. The moſt powerful, and yet the moſt ſimple, of theſe that I have ſeen, are thoſe deſcribed by

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* Briſſon, Traité elementaire de Phyſ. tom. iii. p. 305.

my late valuable friend, Mr. Adams, in his treatiſe of electricity.

Fig. 1. and 2, Plate XXVIII. repreſent two electrical machines of the moſt approved conſtruction; the only difference between them is, the mechaniſm 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 ſeen at *e* and *f*.

The cylinder in Fig. 1. is put in motion by a ſimple winch, which is leſs complicated than that with a multiplying wheel (Fig. 2): as, however, both machines are ſo nearly ſimilar, the ſame letters of reference are uſed in deſcribing them both. A B C repreſent the bottom board of the machine, D and E the two perpendicular ſupports, which ſuſtain the glaſs cylinder F G H I. The axis of the cap K paſſes through the ſupport D; on the extremity of this axis either a ſimple winch is fixed, as in Fig. 1. or a pulley, as in Fig. 2 *. The axis 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.

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* Mr. Adams, in his Lectures on Nat. Philoſophy, obſerves, that machines turned by a ſimple winch are leſs liable to be out of order than thoſe which are turned by a multiplying wheel, and may alſo be excited more powerfully. *Adams's Lect.* vol. iv. p. 311.

Fig. 1.

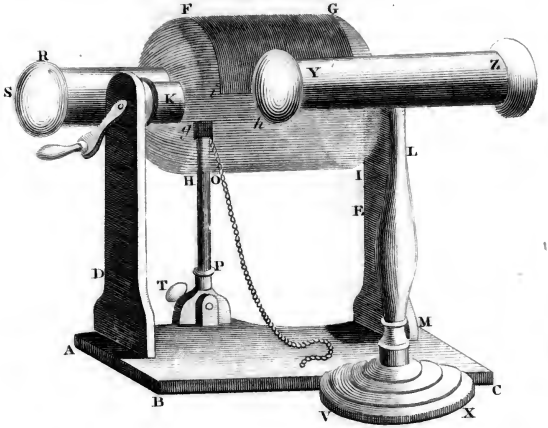
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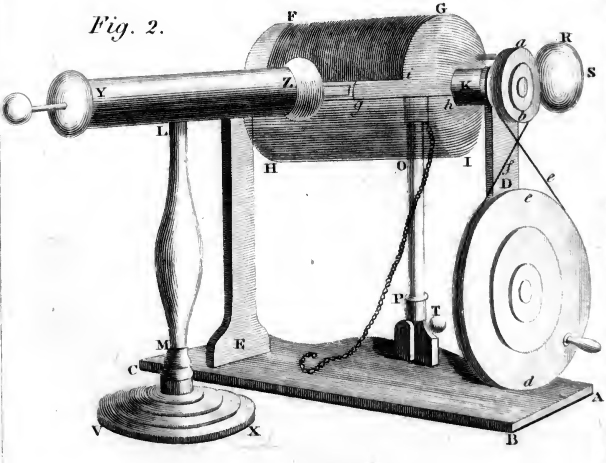
Fig. 2.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On the top of the pillar O P is a conductor, which is connected with the cuſhion, and this is called the negative conductor. In both figures this conductor is ſuppoſed to be fixed cloſe to the cuſhion, and to lie parallel to the glaſs cylinder. 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 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,

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 are now in uſe two kinds of amalgam: One is made of quickſilver five parts, zinc one part, which are melted together with a ſmall quantity of bee's-wax; the other is the aurum muſivum of the ſhops. Before either of theſe will adhere cloſely to the ſilk it is neceſſary to greaſe it, to wipe off the ſuperfluous greaſe, and then ſpread the amalgam.

One property of the electric fluid it will be neceſſary

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* 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 the cylinder by turning it againſt a greaſy leather, till it is uniformly obſcured. The tallow of a candle may be uſed.

'Turn the cylinder till the ſilk flap has wiped off ſo much of the greaſe, as to render it ſemi-tranſparent.

'Put ſome amalgam on a piece of leather, and ſpread it well, ſo that it may be uniformly bright; apply this againſt the turning cylinder, the friction will immediately increaſe, and the leather muſt not be removed until it ceaſes to become greater.

'Remove the leather, and the action of the machine will be very ſtrong.

'The preſſure of the cuſhion cannot be too ſmall, when the excitation is properly made.

'The amalgam is that of Dr. Higgins, compoſed of zinc and mercury; if a little mercury be added to melted zinc, it renders it eaſily pulverable, and more mercury may be added to the powder, to make a very ſoft amalgam. It is apt to cryſtallize by repoſe, which ſeems in ſome meaſure to be prevented by triturating it with a ſmall proportion of greaſe: and it is always of advantage to triturate it before uſing.'

to notice before the concluſion of this branch of the ſubject, and that is, that it is more forcibly attracted by points than by balls or any blunt or rounded ſurfaces. This may be demonſtrated by a variety of eaſy experiments, and may be ſeen by preſenting a metal ball at a given diſtance to a conductor in the act of being charged, when it will be found that a metal point preſented at a much greater diſtance will draw off the whole of the electrical matter from the conductor. In the one caſe alſo (the point) the electricity goes off inviſibly, and without noiſe; in the other caſe there is both a flaſh and a report.

With reſpect to the modes employed by electricians for the accumulation of the fluid, it will be neceſſary to conſider them in a diſtinct chapter; but previous to this a few particulars muſt be ſtated relative to what is termed poſitive and negative electricity.

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 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 appearances 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

has ſtill its ſupporters; amongſt 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.

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*.

7. By exciting an electric, the equilibrium of the fluid is broken, and the one body becomes overloaded with electricity, 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.

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* See Mr. Adams's Lectures on Nat. Phil. vol. iv.

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 different effects on rough and ſmooth bodies, when excited, have been previouſly remarked. 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

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 experiment.

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.*

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 *.

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* 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 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

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.

The moſt uſual forms of the Leyden phial are repreſented in Fig. 3. and 5. Plate XXVII. 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: ſet a plate of glaſs between two metallic plates, about two inches in diameter, ſmaller than the plate of glaſs; charge the 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

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 charging, and negatively, when it is diſcharging*.

When a Leyden phial poſitively charged is inſulated, it will give a ſpark from its knob to an excited ſtick of wax, but not a ſpark will paſs at that time between it and an excited glaſs tube.

An additional quantity of the fluid may be thrown on one ſide of the jar, if by any contrivance an equal quantity may be made to eſcape from the other, and not otherwiſe.

Electricians, in order to increaſe the force of the electric exploſion, connect ſeveral Leyden phials together in a box; and this collection they call an electrical battery.

In this apparatus the bottom of the box (Plate XXVII. Fig. 2.) is covered with tin-foil, to connect the exterior coatings; the inſide 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 ſubſtance may be connected with the outſide coating of the jars; a ball, B, proceeds from the inſide, by which the circuit may be conveniently completed. Mr. Adams gives the following precautions to thoſe who make uſe of an electrical battery †.

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* Mr. Adams's Eſſay on Elect. p. 131.

† Ibid. p. 147.

The top and uncoated part of the jar ſhould be kept dry and free from duſt; and after the exploſion has taken place, a wire from the hook is to be connected to the ball, and left there till the battery 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 a battery is diſcharged through a ſmall ſteel needle,

dle, it will, if the charge is ſtrong, communicate magnetiſm to the needle.

If the diſcharge of a battery paſſes through a ſmall magnetic needle, it will deſtroy the polarity of the needle, and ſometimes invert the poles; but it is often neceſſary to repeat this ſeveral times.

Dr. Prieſtley could melt nine inches of ſmall iron wire at the diſtance of fifteen feet, but at the diſtance of twenty feet he could only make ſix inches of it red hot, ſo that we may infer from this, that notwithſtanding their conducting power, ſtill metals reſiſt in ſome degree the paſſage of the electric fluid, and therefore in eſtimating the conducting powers of different ſubſtances, their length muſt not be forgotten.

If a ſlender wire is incloſed in a glaſs tube, and a battery diſcharged through this wire, it will be thrown into globules of different ſizes, which may be collected from the inner ſurface of the tube; they are often hollow, and little more than the ſcoria or droſs of the metal.

Dr. Watſon and ſome other gentlemen made ſeveral curious experiments to aſcertain the diſtance to which the electric ſhock might be conveyed, and the velocity of its motion, which were briefly mentioned in the firſt chapter. In the firſt experiment, the ſhock was given, and ſpirits fired by the electric matter which had been conveyed through the river Thames. In another experiment, the electric fluid was made to paſs 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.

Notwith-

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 what 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 outermoſt 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 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 XXVI.) 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 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 its 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.

ELECTRICAL PHENOMENA.

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; 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

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 advocates 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 notion 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: as theſe two effects take place in the ſame inſtant, it may be inferred that theſe two currents are ſimultaneous.

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 to require a conſiderable force to ſeparate them. M. Briſſon, who repeated the experiment, obſerves, that after he had ſeparated the white from the black ſtocking another phenomenon occurred; for while he held them, one in each hand, ſuſpended in the air, they ſwelled 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 ruſhed precipitately upon one another, and adhered forcibly together; but this adheſion was not ſo great as that which took place while the ſtockings were one within the other. Mr. Symner ſuppoſed, that the ſucceſs of this experiment depended upon the contraſt between the black and white colour; but M. Briſſon proves

proves this hypotheſis to be without foundation, having made the experiment by ſubſtituting for the black ſtocking another of a different colour, and even a white one; but he confeſſes, that when the experiment was made with two white ſilk ſtockings the effects were weak.

Electrical attraction appears not to be ſo ſtrong in vacuo as in the open air. From ſeveral experiments of Beccaria's we learn, that if the air is thoroughly exhauſted out of a glaſs receiver, the attraction and repulſion of electrified light bodies within the receiver becomes languid, and ſoon ceaſes altogether.

Electricity augments the natural evaporation of fluids, and eſpecially of thoſe fluids which are moſt ſubject to evaporation of themſelves; and it has alſo a great effect on fluids, when the veſſels containing them are non-electrics. If a humid body, a ſponge for inſtance, is placed upon a conductor poſitively electrified, the evaporation will proceed 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.

chine. 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 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

very curious phenomenon has been produced by injecting the electric light in a vacuum.

If a wire with a round end is included 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 length of the receiver, moving with regularity (unleſs it is turned back by ſome non-electric) and then dividing itſelf into a number of beautiful rivulets, which are continually ſeparating and uniting in a pleaſing manner. When the veſſel is graſped by the hand, a pulſation is perceived like that of an artery, and the fire inclines towards the hand. A ſmall quantity of air is, however, neceſſary to occaſion the greateſt luminous effect.

The following is a recapitulation of what M. Briſſon conſiders as fundamental principles, confirmed, he ſays, by his own experiments, ſeconded by thoſe of other philoſophers *.

The electric fluid is the ſame in eſſence with that of light and heat, but combined with a ſubſtance which affects the organs of ſcent.

When bodies are electrified by glaſs, they furniſh tufts or pencils of light; but if electrified by ſulphur or reſinous ſubſtances, they only produce points or ſparks of light; bodies preſented to thoſe electrified by glaſs produce only luminous points, while thoſe which are preſented to bodies which are electrified by ſulphur, produce beautiful pencils or tufts of light.

To electrify bodies by communication, it is neceſſary to inſulate them; the ſubſtances the moſt proper for this purpoſe are thoſe which electrify the beſt by friction.

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* Traité Element. de Phyſique, Tom. iii. p. 435.

Glaſs, though it electrifies very well by friction, electrifies alſo by communication, even without any 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 Lighning.—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 reaſonable demand of an inquiſitive mind: and to ſatisfy this inquiry it will be neceſſary to refer to what has been before obſerved, that this power is produced in two modes, by friction, and by communication. Bodies electrified by friction communicate their

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; and it may be ſuppoſed to have the ſame effect upon thoſe non-electrics which it meets with in its courſe, as our common conductors have upon thoſe which are preſented to them. If a cloud of this kind meets with another which is not electrified, or leſs ſo than itſelf, the electric matter flies off from all parts towards this cloud; hence proceed flaſhes of lightning, and the formidable report of thunder.

‘ Thunder ſtorms,’ ſays Beccaria, ‘ generally happen when there is little or no wind, and their firſt appearance is marked by one denſe cloud, or more, increaſing very faſt in ſize, and riſing into the higher regions of the air; the lower ſurface black, and nearly level, but the upper finely arched, and well defined. Many of theſe clouds ſeem frequently piled one upon another, all arched in the ſame manner; but they keep continually uniting, ſwelling, and extending their arches.

‘ At the time of the riſing of this cloud, the atmoſphere is generally full of a great number of ſeparate clouds, motionleſs, and of odd and whimſical ſhapes. All theſe, upon the appearance of the thunder cloud, draw towards it, and become more uniform in their ſhapes as they approach, till coming very near the thunder cloud, their limbs mutually ſtretch towards one another; they immediately coaleſce, and together make one uniform maſs. But ſometimes the thunder cloud will ſwell, and increaſe very faſt, without the conjunction of any of theſe adſcititious clouds, the vapours of the atmoſphere forming themſelves into clouds wherever 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 adſcititious clouds (the origin of which

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 diſplays a clear ſky.'

It is the opinion of the ſame author, that the clouds ſerve as conductors to convey the electric fluid from thoſe places of the earth which are overloaded with it, to thoſe which are exhauſted of it.

To prove that the earth is often poſitively charged with reſpect to the clouds, in one part while it is negative in another, he adverts to the fall of great quantities of ſand, and other light ſubſtances, which are often carried into the air, and ſcattered 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 againſt the wind; he therefore ſuppoſes, that theſe light bodies are raiſed by a large quantity of electrical matter iſſuing out of the earth.

This comparatively rare phenomenon, he thinks, exhibits both a perfect image and demonſtration of the manner in which the vapours of the atmoſphere are raiſed to form thunder clouds. The ſame electric matter,

matter, wherever it iſſues, attracts to it, and carries into the higher regions of the air, the watery particles diſperſed in the atmoſphere. The electric matter aſcends, being ſolicited by the leſs reſiſtance it finds there than in the common maſs of the earth, which at thoſe times is generally very dry, and conſequently highly electric. The uniformity with which thunder clouds ſpread themſelves, and ſwell into arches, muſt be owing to their being affected by ſome cauſe, which, like the electric matter, diffuſes itſelf uniformly whereever 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 waterſpouts.

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

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, and during the time of rain, but ceaſed a little before the rain was over.

The higher his rods reached, or his kites flew, the ſtronger ſigns they gave of being electrified.

It has been intimated that the clouds are ſometimes poſitively, and ſometimes negatively electrified. In the latter caſe the lightning is ſuppoſed, upon the Franklinian theory, to proceed from the earth to the cloud. The general effects of lightning are preciſely the ſame with thoſe of the electric ſhock, only greatly magnified. It may not be improper in this place to notice an old error, namely, the *melting* of *metals* by what has been called the *cold fuſion*. The error is found to reſt upon certain ill atteſted relations of ſwords being melted in the ſcabbard by lightning, and money in the bag, without injuring the ſcabbard or the bag. A variety of experiments have been accurately made to determine the fact; the reſults of which have been, that the thin edge of the ſword, or of the money, might have been inſtantaneouſly melted, and yet ſo inſtantaneouſly cooled, as neither to affect the ſcabbard nor the bag. A very ſmall wire will inſtantly melt and inſtantly cool in the flame of a common candle.

Mr. Kinneſley incloſed a ſmall wire in a gooſe quill filled with looſe 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 ſame wire; but no ſuch effects could be produced with a wire twice as large. Hence it appears, as Mr. Kinneſley remarks, that though the electrical matter has no ſenſible heat when in a ſtate of reſt, it will, in paſſing through

through bodies, produce heat in them, provided they are proportionally ſmall. Thus, in paſſing through the ſmall wire, the particles are confined to a narrower paſſage, and, crowding cloſe together, act with a more condenſed force, and produce ſenſible heat *.

The diſcovery of Dr. Franklin, which eſtabliſhed the identity of lightning with the electrical fluid, ſuggeſted an invention, for which we are indebted to the ſame philoſopher, for ſecuring buildings from this moſt formidable enemy. The reader will perceive that I allude to that of metallic conductors.

Suppoſe Fig. 4. Plate XXVI. to repreſent the gable end of a houſe, fixed vertically on the horizontal board F G; a ſquare hole is made in the gable end at *h i*, into which a piece of wood is fixed; a wire is inſerted in the diagonal of this little piece; two wires are alſo fitted to the gable end; the lower end of one wire terminating at the upper corner of the ſquare hole, the top of the other wire is fixed to its lower corner; the braſs ball on the wire may be taken off, in order that the pointed end may be occaſionally expoſed to receive the exploſion.

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 diſcharged by an exploſion from the conductor to 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

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* Prieſtley's Hiſt. of Elect. p. 394.

out the little piece of wood to a conſiderable diſtance, by the natural 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 by a gradual current, or by exploſion, will depend upon the ſuddenneſs of the diſcharge, on the nearneſs and motion of the cloud, and the quantity of the electricity contained in it. If a ſmall cloud hangs ſuſpended under a large one loaded with electric matter, pointed conductors on a building underneath will receive the diſcharge by exploſion, in preference to thoſe terminated by balls, the ſmall cloud forming an interruption, which allows only an inſtant of time for the diſcharge *.

Viſcount Mahon (now Earl Stanhope) has com-

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* Mr. Adams's Eſſay on Elect. p. 186.

municated to the public, in a treatiſe on this ſubject *, ſome eſſentials to be obſerved in the erection of conductors to buildings: he adviſes, that the upper fifteen or twenty inches of the rod ſhould be compoſed of copper, and not of iron, as the latter, being expoſed to the weather, will ruſt, and ruſt does not conduct electricity; that the iron part of the rod ſhould be painted, but not the upper part of it, becauſe paint is no conductor. He further adviſes, that the upper extremity of a conducting rod ſhould not only be accurately pointed and finely tapered, but that it ſhould be extremely prominent, about ten or fifteen feet above all the parts of the building which are the neareſt it. It may be added, that a conductor ſhould always be carried in the earth ſome feet beyond the foundation of the building, and ſhould, if poſſible, terminate in water.

The ſafeſt ſituation 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

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* Principles of Electricity, p. 205.

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 Beccaria 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,

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 conſiſts, ſhew the clouds of ſnow to be actuated by ſome uniform cauſe like electricity *.

Conſiſtent with this theory is the fact, that vapours never riſe to a great height without producing meteors. Almoſt all volcanic eruptions are accompanied with lightning. The column of vapour, which proceeds from the bowels of a volcano, is continually traverſed by lightning, which ſometimes ſeems to proceed from the higher regions, ſometimes from the column itſelf. Theſe lightnings were obſerved by the younger Pliny, in the eruption which killed his uncle; and Sir William Hamilton has obſerved them ſeveral times. The aurora borealis is alſo generally ſuppoſed to be electrical; its light ſeems to be produced by the electric fluid, while it is condenſed in paſſing in the columns of elevated vapour †.

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* Prieſtley's Hiſt. Elect. vol. i.

† Mr. Adams's deſcription of this meteor, in his Lectures, is as follows: ' The appearances of the aurora come under four different deſcriptions. 1ſt, A horizontal light, like the morning aurora, or break of day. 2dly, Fine, ſlender, luminous beams, well defined, and of denſe light. Theſe often continue a quarter, an half, or a whole minute, apparently at reſt, but oftener with a quick lateral motion. 3dly, Flaſhes pointing upward, or in the ſame direction as the beams, which they always ſucceed. Theſe are only momentary, and have no lateral motion; but they are generally

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

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generally repeated many times in a minute. They appear much broader, more diffuſe, and of a weaker light than the beams: they grow gradually fainter till they diſappear; and ſometimes continue 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 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.

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 great 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 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 *.

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* 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, 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.

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 occaſionally 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 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 is, an electrical machine with an inſulated cuſhion,

cuſhion, properly conſtructed to afford a continued and ſtrong ſtream of the electrical fluid.

The total want of experimental knowledge upon this ſubject, diſables me from deciding upon the efficacy of this remedy. Electricity 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 doing 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.

CHAP. 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 Air 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 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.

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 produced from the burning of nitre, which air, he obſerved, was very ſoon diminiſhed in bulk, though he did not perceive that the abſorption was owing to the water, which he always uſed in his experiments. The production of an air capable of inflammation from the diſtillation of certain ſubſtances did not eſcape his obſervation; and he has advanced, that the augmentation of weight in the metallic calces was in ſome degree owing to the air which they imbibed. That the phoſphorus of Homberg diminiſhes the air in which it is burned; that nitre cannot explode in vacuo; and that air is in general neceſſary to the cryſtallization of ſalts, are among the facts which are noticed by this philoſopher.

From the uncertainty, however, of Dr. Hales and his predeceſſors, with regard to ſeveral material circumſtances, of which they appear to have had ſome caſual glimpſes, and from their total ignorance of others,

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* See Hales's Vegetable Statics, *paſſim.*

the doctrine of the aerial fluids was but in a ſtate of infancy, till the deciſive experiments of Dr. Black, Mr. Cavendiſh, and Dr. Prieſtley, furniſhed us with a new ſyſtem in this important department of natural hiſtory.

The firſt of theſe philoſophers obſerved, that lime and magneſia, in their mild ſtate, conſiſt of an union of a certain aerial fluid with the earthy baſe; that this aerial matter is actually extracted by the operation of burning, which reduces ordinary calcareous earth to the ſtate of quick-lime; and that it is afterwards re-abſorbed by the quick-lime when expoſed to the air. On this principle he was able, 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 differed 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, is 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 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 calcination of metals is owing to the abſorption of a certain elaſtic fluid; but he did not at firſt perceive that this fluid was in any reſpect different from the fixable air produced by efferveſcing mixtures. In a memoir, however, which he read after the publication of his eſſays, before the French

French Academy, he was 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 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

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* Prieſtley on Air, vol. ii. p. 36, and 320.

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 with inflammable air in a due proportion, and paſſing through them an electric ſpark, 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 chemiſts, who have proved that azotic, 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.

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* 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. 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 Gas.—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

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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 baſis 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 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 ſucceeding experiments of Dr. Prieſtley and others it however appears, that dephlogiſticated or oxygen air, may be obtained not only by means of heat, but alſo by the action of the vitriolic and nitrous

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* From Oξυς (oxus) "ſharp or acid," and γεινομαι (ginomai) "to beget or produce."—Oxygen is then literally the principle or ſubſtance producing acids.

Fig. 4.

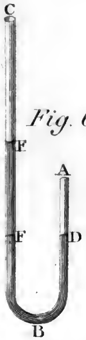



Fig. 6.

Fig. 5.

Fig. 1.

Fig. 2.

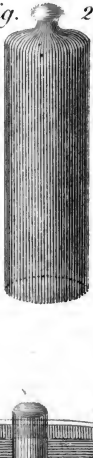
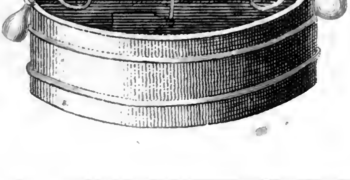


Fig. 3.



acids upon a variety of mineral and metallic ſubſtances.

In a ſmall phial A B (Plate XXIX. 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 ſame proceſs, from the native oxid or calx of manganeſe, or from minium or red lead, which, it is well known, is an oxid of lead, or lead united with oxygen.

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

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* Traité Elem. de Phyſ. tom. ii. p. 24.

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-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 of the fixed air, and leave the dephlogiſticated air or oxygen gas by itſelf.

Oxygen gas may alſo be obtained in conſiderable

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* Briſſon, tom. ii. p. 25.

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, in 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, when expoſed to the action of the ſun for a conſiderable time.

The ingenious Count Rumford obſerved, that raw ſilk has a remarkable power of producing pure air from water. He found, that by introducing thirty grains of this ſubſtance, firſt waſhed in water, into a thin glaſs 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 in a jar filled with the ſame kind of water, and expoſing it to the action of the ſun in the window, in leſs than ten minutes the ſilk became covered with an infinite number of air bubbles, gradually increaſing in ſize, till at the end of two hours the ſilk was buoyed up, by their means, to the top of the water. They ſeparated themſelves by degrees, and formed a collection of air in the upper part of the globe, which, when examined by the eſtabliſhed teſt, 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 juſt before been blown out, the wick only remaining red, it inſtantly took fire, and burned with a bright and enlarged flame. The water in the globe had acquired the ſmell of raw ſilk, it loſt ſomething of its tranſparency, and aſſumed a faint greeniſh caſt.

It was obſerved, that when this experiment was made in the dark, only a few inconſiderable bubbles were formed, which remained attached to the 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

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. Its baſis oxygen 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. 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 of 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. When after this proceſs 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 lime water or 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,

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three, or four times better than common air. Dr. Prieſtley mentions ſome extracted from red lead five times as pure as common air.

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 fluid; 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 for which it has itſelf a ſtrong attraction. 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 carbonic acid 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 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 the attraction of 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; and this is conſonant with the obſervations of phyſicians, who have attempted to cure pthiſis 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; 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 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 was at firſt 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 gas, 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 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

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* 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.

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 neceſſary 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 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 not ſuſtaining the vital principle in 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.

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* 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.

† Animal life, however, does not appear to be deſtroyed by any noxious quality in this air, as is the caſe in breathing fixed air; but the animal dies for want of the neceſſary pabulum of oxygen gas.

4thly.

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 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.

As this air conſtitutes ſo large a proportion of the common air which we breathe, its further uſes and properties will be better explained when I come to treat of the atmoſphere.

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* Briſſon, tom. ii. p. 35.

† It may perhaps be neceſſary to inform the young 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*.

CHAP. IV.

OF CARBONIC ACID GAS; FIXED OR FIXABLE AIR.

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 elementary 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.

As this was the firſt of the gaſſes which excited the attention of the philoſophers of Europe, it has been diſtinguiſhed by various appellations. It was at firſt only known under the general and uncharacteriſtic name of mephitic or (foul) air; when it was found exiſting in large quantities in a fixed or ſolid ſtate, as in lime, chalk, or alkaline ſalts, from which it might be expelled by the action of heat, it obtained the name of *fixed* or *fixable* air; when by the uſual teſts, and by other infallible marks, it was found to poſſeſs the characters of an acid, it was called by the learned Bergman

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the *aerial acid*, becauſe it could be obtained only in a pure or uncombined ſtate in an aerial form; and from its exiſting in conſiderable quantity in chalk, &c. it was denominated by other chemiſts the *cretaceous* or chalky acid. I have preferred the name which has been adopted by the judicious Lavoiſier, as more immediately expreſſive of its characteriſtic, and peculiar baſis, which is undoubtedly the matter of coal.

The proportion of the materials which enter into this kind of air is about eighteen parts of oxygen and ſeven 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 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 ſacharine 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. 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 ½ 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 ¼

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, 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

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 the greater weight of this gas it always falls to the bottom of the veſſel in which it is contained. An animal (as was before obſerved) 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. 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 burning coals; let a crooked tube placed at the end of this iron, and

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* Ὕδωρ (hydor) "water" and γεινομαι (geinomai) "to produce."

† Briſſon, tom. ii. p. 73.

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. Cavallo informs us, that he has procured this kind of air from the ponds about London, in the folling 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

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 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 *.

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 metalic 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,

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* See Briſſon, tom. ii. p. 77.

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 Abbé 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 pleaſing fireworks may be made from this gas, by filling bladders with it, and fixing braſs cocks to them, by means of which the gas may be diſperſed into any number of glaſs tubes bent in various ſhapes, and with ſmall holes in various parts of them; then by preſſing the bladders more or leſs, as occaſion may require, the gas will paſs into the tubes, and iſſue out of the ſmall holes, to which a lighted taper may be applied; by theſe means the air will take fire, and will continue to burn until the courſe of it is ſtopped by ſhutting the cock at the neck of the bladder. Theſe aerial fireworks may be made to repreſent different figures, either movable 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 atmoſpheric air, a flame of a blue colour will be produced; the pure hydrogen from metals furniſhes a red flame; and if by breathing, ſome carbonic acid gas or fixable air is added, the flame will appear beautifully tinged with purple *.

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* See Briſſon, 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, according to the ſtrength which is required. Nitrous air contains, in 100 grains, 68 of oxygen, and 32 of azote.

On its relation to the nitrous acid the diſtinguiſhing properties of this gas will be found to depend.

1ſt. Nitrous air is as inviſible and tranſparent as common air; in its ſmell it reſembles nitrous acid. Though this

this kind of air extinguiſhes flame, it may, by certain proceſſes, be brought to ſuch a ſtate. that a candle will burn in it with an enlarged flame, and it then becomes what Dr. Prieſtley calls *dephlogiſticated nitrous air*. Its ſupporting flame in this inſtance evidently depends on the large quantity of oxygen which enters into its compoſition.

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. Cavendiſh impregnated fifty ounces of diſtilled water with fifty-two ounce meaſures of nitrous air, mixed with as much common air as was neceſſary to decompound it. The water thus impregnated was ſenſibly acid, and being diſtilled, the firſt runnings were very acid, and ſmelt pungent: what came next had no taſte or ſmell; but the laſt runnings were very weak nitrous acid *.

3d. Of all the different ſpecies of air, this ſeems the moſt noxious to animal life. Inſects, which can bear azotic and inflammable air, will die immediately upon their being immerſed in this. Even fiſhes will not live in water impregnated with it.

It may ſeem extraordinary that nitrous gas, which is of ſo deleterious a nature, and ſo oppoſite in its qualities to common air, ſhould yet ſubſtantially conſiſt of the ſame principles, differing, however, in the proportions. To remove the difficulty, it will be neceſſary to recollect what has been more than once intimated concerning the difference between *mixture* and *combination*. In ſimple mixture the two bodies ſtill retain their own diſtinct properties; but in chemical combination a third ſubſtance is formed from the two, entirely different from both in its nature and properties. Thus, from

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* Phil. Tranſ. for 1784.

marine

marine acid or ſpirit of ſalt, and cauſtic alkali, both extremely corroſive, is formed that innocent and wholeſome ſubſtance, common ſalt; and from two ſubſtances innoxious to the human frame, ſulphur and oxygen, vitriolic acid, or ſpirit of vitriol, is formed. In common air, azote and oxygen are indeed in a ſtate of mixture, but they are not combined; for to make them enter into a ſtate of combination, the operation of a ſtrong agent, ſuch as fire from the electric ſpark, is neceſſary, and without this, azote appears to have little or no attraction for oxygen. In the ordinary proceſs of reſpiration the mixed ſubſtances are inhaled; and it is probable that they are ſoon again ſeparated in this proceſs, and each differently diſpoſed of. In nitrous gas, the azote and oxygen are in a ſtate of chemical combination, and it is a third ſubſtance different in qualities from both; it is, 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 air 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 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 condenſation of the nitrous air; but as the air of 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

mon 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 in a gradual way.

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.

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 a combination of pure hydrogen and ſulphur. The moſt proper method of obtaining it 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 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 will be deſcribed in treating of vitriolic ſalts.

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[*] A ſubſtance uſually formed from fixed alkali, or ſalt of tartar, and ſulphur, combined by heat.

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 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 homogenous 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 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 gradual introduction of nitrous air into 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; the ſame quantity is in effect deſtroyed by the combuſtion of any inflammable ſubſtance, and the combuſtion gradually ceaſes 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 it is found by experiments with the eudiometer, that the upper regions of the air actually contain a greater proportion of oxygen than thoſe nearer the ſurface of the earth. Whether this is to be attributed to the attraction which azote may have for the earth, or to ſome unknown property in the oxygen, we cannot now determine, and can only take the fact as it ſtands, without attempting its explanation *.

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* A mixture of empyreal and inflammable airs (the latter of which is much lighter than the former) remaining all night, was found the next morning in the moſt perfect ſtate of mixture, and the electric ſpark paſſed through them with the uſual effect. *Prieſtley's Experiments*, vol. vi. p. 27.

From the great conſumption of oxygen by various natural and artificial proceſſes, it might be expected that a deficiency of this fluid in the atmoſphere might ſometimes occur; but the wiſdom of Providence is evident in this, as well as in every other inſtance; for we have already ſeen that the proceſſes in nature which deſtroy this air are nearly balanced by thoſe which produce it. A ſeries of experiments were made at Stockholm by the indefatigable Scheele, to aſcertain the goodneſs of the air during every day in the courſe of a year. He found that the diminution by the eudiometer never exceeded one-third, nor was leſs than eight thirty-thirds. The quantity of vital air was leaſt in March, November, and December, and in general leſs in the winter than in the ſummer months, which may be attributed to the redundant ſupply of this matter by the copious vegetation which takes place at that period. The air 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 moderare 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 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 gunpowders by oil paints, by the volatile ſpirit of ſal ammoniac, by ſpirit 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 mephitic 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

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* 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.

what with the preſent evaſion of that act, the depoſiting in vaults, and the frequent breaking up of the ground, and removing putrid bodies, the caſe is not much better; and indeed much might yet be done to render the air of London more ſalubrious than it is.

I have taken no notice of the accounts which ſome ingenious men have afforded us of the ſalubrity of the air in different places, convinced that we are not as yet poſſeſſed of a complete teſt of the ſalubrity of air; and till this can be procured our only guide muſt be experience.

By agitating putrid and inflammable air in diſtilled water, or water from which the air has been expelled by boiling, a conſiderable diminution will take place, ſometimes above a third of the bulk, and the air will be conſiderably purified. Thus the agitation of the ſea, and of large lakes, has probably the happieſt effect in purifying the atmoſphere.

Dr. Hales found that air might be breathed much longer, when in the act of reſpiration it was made to paſs through ſeveral folds of cloth dipped in vinegar, a ſolution of ſea ſalt, or oil of tartar, than when no ſuch contrivance was uſed *; the reaſon of which is briefly, that theſe ſubſtances abſorb the fixable air which comes from the lungs.

Putrid air was alſo reſtored by a mixture of carbonic acid air. The experiment was, however, in ſome meaſure rendered doubtful by the air having been paſſed through a veſſel of water in order to its admixture. If, however, the fact is well founded; 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.

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* Hale's Eſſ. p. 266.

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 coldneſs is increaſed. Every body knows how very diſagreeable a very moderate degree of cold is when it is very damp; and hence it appears, why the thermometer is not always a juſt meaſure of the apparent or ſenſible heat of the atmoſphere. If colds or catarrhs are occaſioned by our bodies being robbed of our animal heat, the reaſon is plain why thoſe diſorders prevail moſt during the cold autumnal rains, and upon the breaking up of froſt in the ſpring. It is likewiſe plain, whence it is that ſleeping in damp beds and inhabiting damp houſes is ſo very dangerous, and why the evening air is ſo pernicious in ſummer and autumn, and why it is not ſo in the hard froſts of winter. It has puzzled many to account for the manner in which ſuch an extraordinary degree, or rather quantity of heat is generated, which an animal body is ſuppoſed to loſe if expoſed to the cold of winter, which it communicates to the ſurrounding atmoſphere in warm ſummer weather; but is it not more than probable, that the difference of the quantities of heat actually loſt or conſumed, is infinitely leſs than what they have imagined*?'

Various inſtruments have been invented under the general name of hygrometers†, for aſcertaining the quantity of moiſture contained in the atmoſphere. Moſt bodies attract moiſture, and are expanded by it. Wood and other ſolid bodies are ſwelled by the moiſture inſinuating itſelf between the fibres, and conſequently a piece of wood cut tranſverſely, will be extended in length by the abſorption of damp or wet. Cord, catgut, &c. the fibres of which extend longitudinally, will increaſe in thickneſs, but will contract in length on the application of moiſture. On this laſt principle the common weather-houſe is conſtructed, which is no bad hygrometer for general purpoſes; the contraction of the ſtring by wet forces the man out of the door, and when by the return of fine weather the ſtring or catgut is diſpoſed to reſume its natural length, an elaſtic wire acts upon it, and the woman appears. The firſt regular and graduated hygrometer that deſerves to be mentioned, as made in this country, was

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* Thompſon's Experiments. Phil. Tranſ. Vol. lxxvi.

† Ὑγος, (hygros) "moiſture;" and Μετρον, (metron) "a meaſure."

that of the late ingenious Mr. Smeaton. He employed in its conſtruction a flaxen ſtring of three threads, commonly uſed in making nets, which, in order to make it attract the moiſture readily, he ſteeped in ſalt and water. This he extended along a board properly graduated, and to one part contrived to attach an index, which ſerved to ſhew its variations. M. Sauſſure employed a hair for the ſame purpoſe, which he ſuſpended by a weight of three grains, and contrived it to act upon an index pointing to a graduated ſcale; and this was found to be a very delicate and accurate inſtrument.

M. de Luc, however, conceived that a ſolid 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

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 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 botaniſts have aſſerted, that the variation of climate in aſcending mountains, was diſcernible 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 ſummit.

Different opinions have been entertained concerning the cold in elevated ſituations. It was for a conſiderable time imagined, that it depended altogether on the rarity of the atmoſphere in thoſe regions, which is very conſiderable; but it has been remarked, on the authority of Count Rumford, that the rarity or denſity of the air appears to have little effect on its conducting power. Some have ſuppoſed, that as the air is ſo much rarer in the upper regions, leſs fire or caloric is required to keep it in a ſtate of fluidity, and conſequently that there is a real deficiency of that element. The hypotheſis of M. Bouguer *, however, comes recommended by its ſimplicity, and by its agreement with moſt of the other phenomena of heat, and I ſhall therefore adopt it with only ſome ſlight variations.

Without entering into the controverſy concerning the identity of fire and light, it is only neceſſary to aſſume as a principle the well known circumſtance,

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* Reaſons for the cold on the top of the Andes.

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 ſpirit is 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 it; if, however, the ſpirit is 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 ſpirit 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 ſpirit incloſed in a clear glaſs veſſel; and there is a 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

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 Antients.—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 it 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 that always tends to dilate the maſs, and 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

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 a vacuum, 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 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,

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* Briſſon, Tom. ii. p. 93.

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 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, Torricelli, 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 about three feet in length and two or three lines 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

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* Cloſed by melting the glaſs, and conſolidating it.

inches long, was reduced to the length of about twenty-eight inches. Now, if we compare the experiment of Galileo with that of Torricelli, 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 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 fixed a tube of Torricelli's upon a perpendicular plank (ſee Plate XXIX. 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 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

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ſame which is 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 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,

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* "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 re-aſcends, 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.

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 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

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* Briſſon. Vol. i.

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 ſames bodies when expoſed to air, we require a knowledge of the effects of that fluid 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 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 XXX. 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 action 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

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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

the valves, and then no more can be taken out of the receiver. Hence it appears, that 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.

Such 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 LL, 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 a 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 LL. 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 will

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* Goldſmith's Philoſophy, vol. ii. p. 56.

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 into 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.

By means of its gravity, the atmoſphere preſſes with great force upon all bodies, according to the extent of their ſurface. According to M. Paſchal, the quantity of this preſſure is not leſs than 2,232 pounds upon every ſquare foot of ſurface, or upwards of fifteen

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* 253.18 grains. Decimal arithmetic ſhould always be employed in philoſophical calculations, for the ſake of accuracy.

teen 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 fear-"fully 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 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, becauſe the column of air is enlarged in proportion to the diameter of the aperture.

Our ſurpriſe is excited by obſerving, that notwithſtanding this great preſſure upon a glaſs receiver, when a vacuum is obtained, the glaſs is not daſhed to pieces as might be expected. Its preſervation is in a great meaſure owing to the rotundity of its figure, and to the exceſs of the exterior ſurface over the interior; for the ſubſtance which compoſes the body of the veſſel reſembles, in this caſe, the ſubſtance which compoſes an arch in a bridge. We may be convinced of the truth of this obſervation by taking a receiver of another

ther form, that is open at both ends, and covered with a bladder at the top, and beginning to exhauſt the air, when the bladder will infallibly be burſt by the preſſure of the exterior atmoſpheric air.

This gravity of the atmoſphere accompliſhes many uſeful purpoſes in nature, ſuch as preventing the blood veſſels of animals, and the ſap veſſels of plants, from being too much diſtended by the expanſive power, which has a perpetual tendency to ſwell them out. On this account we ſee, that in the operation of cupping, where the preſſure of the air is taken off from a particular part, the expanſive force inſtantly acts, and ſwells out the veſſels to a great degree. This is alſo the reaſon why the bodies of animals ſwell when they are put into an air-pump. It is owing to the gravity of air that ſubſtances remain liquid, which would become aeriform in 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

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 has more denſity 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 XXIX. 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 equilibrium with FB; conſequently the quickſilver contained between FD will not at all preſs on the air between A and D;

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* Lavoiſier's Elem. of Chemiſt. p. 8.

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 the ſpaces into which the air is condenſed by different weights, bear a regular proportion to thoſe weights, and its denſity is conſequently increaſed in proportion to the degree of preſſure exerted upon it.

It is, however, very probable, after all, that this compreſſion has its limits, 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 allowed to depend upon the latent caloric 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

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placed under the receiver 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 encloſed 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 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 inſtru-

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[*] Briſſon, tom. ii. p. 103.

[†] Elem. of Chem. p. 22.

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ments 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 XXX. 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 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

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 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 al-

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* Goldſmith's Philoſophy, Vol. II. p. 96.

ternately, 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 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 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,

ments, 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.

5 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 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

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 circumſtances with the received theory of the height of the atmoſphere; as, in the regions in which this meteor moved, the air ought to have been three hundred thouſand times more rare than what we breathe, and the next thing to a perfect vacuum.

'In the meteor of 1783, the difficulty is ſtill greater, as it appears to have been twenty miles farther up in the air. Dr. Halley offers a conjecture, indeed, that the vaſt magnitude of ſuch bodies might compenſate for the thinneſs of the medium in which they moved; whether or not this was the caſe, cannot indeed be aſcertained, as we have ſo few data to go upon; but the greateſt difficulty is to account for the brightneſs 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 eaſe the vacuum of a common air-pump, yet it does not in that caſe appear in bright well defined ſparks as in the open air, but rather in long ſtreams reſembling the aurora borealis. From ſome late experiments, Mr. Morgan concludes that the electrical fluid cannot penetrate a perfect vacuum. If this ſhould be the caſe, it ſhews that the regions we ſpeak of are not ſuch a perfect vacuum as can be artificially made; but whether they are or not, the extreme brightneſs of the light ſhews that a fluid was preſent in thoſe regions, capable of confining and condenſing the electric matter as much as the air does at the ſurface of the ground; for the brightneſs of theſe 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

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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 *.'

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* Adams's Lectures, vol. i. p. 52.

CHAP. X.

OF SOUND.

Sound conſidered in Three Points of View.—Cauſed by a Vibration in the Parts of Bodies.—Propagated by an undulatory Motion of the Air.—This proved by Experiment.—Glaſſes broken by an Effort of the Voice.—Elaſtic Fluids not the only Means of tranſmitting Sound.—Water or ſolid Bodies convey it.—Velocity of Sound.—Experiments on this Subject.—Echoes.—Whiſpering Gallery.

THERE is another property of air, which could not ſo conveniently be introduced into the preceding chapter; I mean the power of tranſmitting ſounds.

Sound is produced by a vibrating motion, excited in a ſonorous body by a blow or a ſhock from another body, and the ſame motion is communicated by this ſonorous body to the fluid which ſurrounds it, and tranſmitted by this fluid to the ear, which is an organ admirably adapted to receive its impreſſion.

From this definition it follows, that ſound ſhould be conſidered in three different views; firſt, with reſpect to the ſonorous body which produces it; ſecondly, as to the medium which tranſmits it; and, thirdly, as to the organ which receives the impreſſion.

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,

Fig. 3.

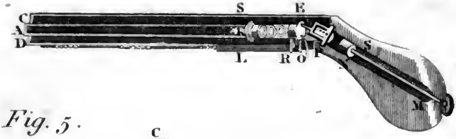

Fig. 5.

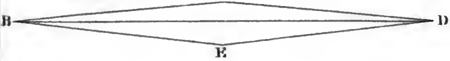

Fig. 4.

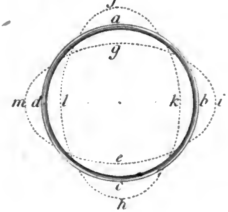

Fig. 1.

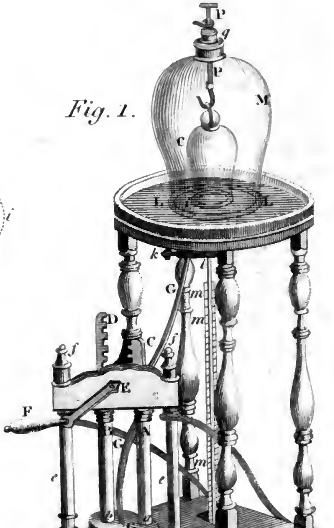

Fig. 2.

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 XXX. 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 *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

ticles 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 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

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* Mem. de l'Acad. 1716, p. 264.

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.

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* 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.—*Traité Elem. de Phyſique,* tom. ii. p. 162.

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 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 medium 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.

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* Elem. de Phyſique, tom. ii. p. 164.

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

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* 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 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

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 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 gunpowder exploded at Montmartre 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 the whole courſe of its progreſs.

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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.

progreſs. 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 feet in one ſecond, this number multiplied by 5 gives the diſtance of 5710 feet. The ſame principle has been already mentioned as applicable in 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

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* "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 the contrary, thoſe who ſtood at ſome diſtance, heard the echo but not the voice; but then they heard it with ſurpriſing variations, ſometimes louder, ſometimes ſofter, now more near, then more diſtant. There is an account, in the memoirs of the French academy, of a ſimilar echo near Rouen. The building which returns it is a ſemicircular court-yard; yet all buildings of the ſame form do not produce the ſame effects. We find ſome muſic halls excellently adapted for ſounds, while others, built upon the ſame plan, in a different place, are found to mix the tones, inſtead of enlarging them, in a very diſagreeable manner.

"As we know the diſtance of places by the length of time a ſound takes to travel from them, ſo we may judge of the diſtance of an echo, by the length of the interval between our voice and its repetition. The moſt deliberate echoes, as they are called, are ever the moſt diſtant; while, on the contrary, thoſe that are very near, return their ſounds ſo very quick as to have the interval almoſt imperceptible; when this is the caſe, and the echo is ſo very near, the voice is ſaid to be increaſed and not echoed; however, in fact, the increaſe is only made by the ſwiftly purſuing repetition. Our theatres and concert rooms are beſt fitted for muſic or ſpeaking, when they enlarge the ſound to the greateſt pitch at the ſmalleſt interval: for a repetition which does not begin the

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Reflected ſound may be magnified by much the ſame contrivances as are uſed in optics reſpecting light: hence it follows, that ſounds utered 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 economy which reſpects the ſenſe of hearing.

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word till the ſpeaker has finiſhed it, throws all the ſounds into confuſion. Thus the theatre at the Hay-market enlarges the ſound very much; but then at a long interval after the ſinger or ſpeaker. The theatre at Drury-lane, before it was altered, enlarged the ſound but in a ſmall degree; but then the repetition was extremely quick in its purſuit, and the ſounds, when heard, were therefore heard diſtinctly. Dergoliſe, the great muſical compoſer, uſed to ſay, that an echo was the beſt ſchool-miſtreſs; for let a man's own muſic be ever ſo good, by playing to an echo ſhe would teach him to improve it."—*Goldſmith's Philoſophy*, vol. ii. p. 201—204.

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.—Waterſpouts.—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, and 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

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 farther 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

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[*] With reſpect to 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.

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, there are calms, variable winds, and tremendous ſtorms, with thunder, &c.

Philoſophers differ in their opinions reſpecting the cauſe of theſe periodical winds; but a moſt probable theory of the general trade-winds is, that they are occaſioned by the heat of the ſun in the regions about the equator, where the air is heated to a greater degree, and conſequently rarefied more than in thoſe parts of the globe which are nearer the poles. From this expanſion of the air in theſe tropical regions, the denſer air, in higher latitudes, ruſhes violently towards the equator from both ſides of the globe. By this conflux of the denſer air, without any other circumſtances intervening, a direct northerly wind would be produced in the north-

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* See Nicholſon's Phil. vol. ii. p. 56.

ern tropic, and a ſouthern one in the other tropic; but as the earth's diurnal motion varies the direct influence of the ſun over the ſurface of the earth, and as by that motion this influence is communicated from eaſt to weſt, an eaſterly wind would be produced, if this influence alone prevailed. On account of the co-operation of theſe two cauſes at the ſame time, the trade-winds blow naturally from the N. E. on the north, and from the S. E. on the ſouth of the line, throughout the whole year; but as the ſun approaches nearer the tropic of *Cancer* in our ſummer ſeaſon, the point towards which theſe winds are directed will not be invariably the ſame, but they will incline more towards the north in that ſeaſon, and more towards the ſouth in our winter.

The *land* and *ſea breezes* in the tropical climates may be conſidered as partial interruptions of the general 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 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

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, 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 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: on the contrary, at land, the weſt and ſouth winds moſt frequently 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

'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 heights 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 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 ſometimes 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*.'

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, and which are commonly denominated hurricanes.

Theſe dreadful convulſions of nature, Dr. Perkins, of Boſton, in America, 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

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* Goldſmith's Philoſophy, vol. ii. p. 143.

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;

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* American Phil. Tranſ. vol. 1.

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 to pieces; their houſes are no protection; their roofs are torn off at one blaſt, whilſt the rain 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*.'

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* Adams's Lectures, vol. iv. p. 540.

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, January, and February; it comes on indiſcriminately at any hour of the day, at any time of the tide, or at any period of the moon, and continues ſometimes only a day or two, ſometimes five or ſix days, and it has been known to laſt fifteen and ſixteen days. There are generally three or four returns of it every ſeaſon. It blows with a moderate force, but not quite ſo ſtrong as the ſea breeze.

A fog or haze is one of the peculiarities which always accompany the harmattan. The Engliſh, French, and Portugueſe forts at Whydah, are not quite a quarter of a mile aſunder, yet are frequently quite inviſible to each other; the ſun, concealed the greateſt part of the day, appears only about a few hours at noon, and then of a mild red, exciting no painful ſenſation on the eye. The particles which conſtitute this fog are depoſited on the leaves of trees, on the ſkins of the negroes, &c. and make them appear whitiſh.

Extreme dryneſs makes another extraordinary property of this wind; no dew falls during its continuance; vegetables are withered, and the graſs becomes dry like hay. The natives take this opportunity to clear the land, by ſetting fire to the trees and plants while in that dry and exhauſted ſtate. The dryneſs is ſo extreme, that the covers of books, even cloſely ſhut up in a trunk, are bent as if expoſed to the fire. Houſhold furniture is much damaged; the pannels of wainſcots ſplit, and fineered work flies to pieces. The joints of a well-laid floor of ſeaſoned wood open ſufficiently to admit the breadth of a finger between them; but become as cloſe as before on the ceaſing of the harmattan.

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 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

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* Dobſ. Account. Phil. Tranſ. vol. lxxi. part 1.

wind has continued a whole night, to inquire who is dead *.

Whether

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* ‘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 was 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 conſequence of the duration of its ſcorching heats in ſeveral parts of Italy, though its violence in thoſe countries is much inferior to what is felt in this iſland. Here it ſeldom endures longer than thirty-ſix or forty hours, a time not ſufficient to heat the ground, or the walls of the houſes, in a very intenſe continued degree. It is commonly ſucceeded by the tramontane, or north wind, which in a ſhort time reſtores the exhauſted powers of animal and vegetable life, and nature ſoon aſſumes her former appearance. The cauſe of the ſirocc wind has been frequently attempted to be explained, but the different hypotheſes are perhaps more to be admired for their ingenuity and fancy than for being very ſatisfactorily explained. The ſuperior intenſeneſs of this ſcorching wind at Palermo, may probably be accounted for from the ſituation of that city, which is almoſt ſurrounded by lofty

Whether the fatal effects of the ſirocco depend entirely upon the degree of fever, which is produced by the extreme heat which accompanies it, or whether it is really charged with any mephitic gas, I have never been ſufficiently informed; but I wiſh that any intelligent traveller would examine the ſtate of the air by the eudiometer, and by other teſts, during the prevalence of this wind. Should it be found loaded with carbonic gas, its ill effects might eaſily be obviated by ſuſpending, in the different apartments, cloths dipped in lime water; but from the preſent ſtate of the evidence I am diſpoſed to think that all its evil conſequences depend upon the ſudden increaſe of the temperature only.

'An extraordinary blaſting wind is felt occaſionally at Falklands Iſlands. Happily its duration is ſhort: it ſeldom 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 duſt. Fowls are ſeized with cramps ſo as never to recover. Men are oppreſſed with a ſtopped perſpiration, heavineſs at the breaſt, and ſore throat; but uſually recover with care.

'But beyond all others in its dreadful effects, is the ſamiel, or mortifying wind, of the deſerts near Bagdad. The camels, either by inſtinct or experience, have

lofty mountains, the ravines and valleys of which are parched and almoſt burnt up in ſummer. The numberleſs ſprings of warm water muſt alſo greatly increaſe the heat of the air, and the practice of burning bruſh wood and heath on the neighbouring mountains, during the warm ſeaſon, muſt undoubtedly tend to increaſe the heat of the wind in paſſing over the country of Sicily, though it had previouſly been diſarmed of part of its violence by travelling over the ſea which divides Sicily from Africa." *Preſent State of Sicily and Malta*, p. 189.

notice

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. Its fatal effects, if the ſtatement is perfectly correct, evidently proceed from a certain portion of extremely putrid vapours with which it is charged, and I ſuſpect it only happens when a ſtrong wind chances to blow over ſome very putrid and ſtagnant lake, which is not far diſtant; travellers, however, are on ſuch occaſions commonly in a ſtate of too much alarm to note circumſtances with accuracy, and too much of their accounts is collected upon hear-ſay evidence. This wind, after all, may only conſiſt of a mephitic vapour which deſtroys life when inhaled; and the putridity, which is ſaid ſo rapidly to take place, may depend more upon the climate than the nature of the wind.

A wind or haze was obſerved by Mr. Bruce, in the courſe of his travels to diſcover the ſources of the Nile, reſembling the preceding in ſome of its effects, though

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* See Adams's Lectures, vol. iv. p. 541.

though in others it may be thought more analogous to the ſirocco. It is called by Mr. Bruce the ſimoom, and from its effects upon the lungs, I can entertain but little doubt, that it conſiſts chiefly of carbonic acid gas in a very denſe ſtate, and perhaps mixed with ſome other noxious exhalations.

In the ſame deſert Mr. Bruce obſerved the aſtoniſhing phenomenon of moving pillars of ſand*; which are probably the effects of a number of whirlwinds in thoſe torrid regions. As the deſcription of theſe pillars is in ſome degree blended with that of the ſimoom, I ſhall extract the whole paſſage. In relating the particulars of his journey acroſs a certain part of the deſerts of Africa, Mr. Bruce obſerves, ' We were here at once ſurpriſed and terrified by a ſight ſurely one of the moſt magnificent in the world. In that vaſt expanſe of deſert, from weſt and to the north weſt of us, we ſaw a number of prodigious pillars of ſand at different diſtances, at times moving with great celerity, and at others ſtalking on with a majeſtic ſlowneſs; at intervals we thought they were coming in a very few minutes to overwhelm us; and ſmall quantities of ſand did actually more than once reach us. Again they would retreat ſo as to be almoſt out of ſight, their tops reaching to the very clouds. There the tops often ſeparated from the bodies; and theſe, once disjoined, diſperſed in the air, and did not appear more. Sometimes they were broken near the middle, as if ſtruck with a large can-

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* " So where our wide Numidian waſtes extend,
Sudden th' impetuous hurricanes deſcend,
Wheel through the air, in circling eddies play,
Tear up the ſands, and ſweep whole plains away;
Th' affrighted traveller, with wild ſurpriſe,
Sees the dry deſert all around him riſe,
And, ſmother'd in the duſty whirlwind, dies."

Addiſon's Cato.

non ſhot. About noon they began to advance with conſiderable ſwiftneſs upon us, the wind being very ſtrong at north. Eleven of them ranged alongſide of us about the diſtance of three miles. The greateſt diameter of the largeſt appeared to me at that diſtance, as if it would meaſure ten feet. They retired from us with a wind at ſouth eaſt; leaving an impreſſion upon my mind to which I can give no name, though ſurely one ingredient in it was fear, with a conſiderable deal of wonder and aſtoniſhment. It was in vain to think of flying; the ſwifteſt horſe, or faſteſt ſailing ſhip, could be of no uſe to carry us out of this danger; and the full perſuaſion of this rivetted me as if to the ſpot where I ſtood, and let the camels gain on me ſo much in my ſtate of lameneſs, that it was with ſome difficulty I could overtake them.'

The ſame phenomena again occurred in the courſe of a few days. 'The ſame appearance of moving pillars of ſand preſented themſelves to us this day, in form and diſpoſition like thoſe we had ſeen at Waadi Halboub, only they ſeemed to be more in number, and leſs in ſize. They came ſeveral times in a direction cloſe upon us; that is, I believe, within leſs than two miles. They began immediately after ſun-riſe, like a thick wood, and almoſt darkened the ſun: his rays ſhining through them for near an hour, gave them an appearance of pillars of fire. Our people now became deſperate: the Greeks ſhrieked out, and ſaid it was the day of judgment. Iſmael pronounced it to be hell, and the Tucorories, that the world was on fire. I aſked Idris if ever he had before ſeen ſuch a ſight? he ſaid he had often ſeen them as terrible, though never worſe; but what he feared moſt was the extreme redneſs of the air, which was a ſure preſage of the coming of the ſimoom. I begged and intreated Idris that he would not ſay one word

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 Mout, 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 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 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

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* Bruce's Travels, vol. iv. p. 553, 555.

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 rarefied, 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

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* Philad. Tranſ. vol. ii.

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 undergoes 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 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, 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. 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 violent in its effects. It commences very ſuddenly, ſeveral

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* Philad. Tranſ. vol. ii.

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 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 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.

METEOROLOGY, 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 from the preſent chapter. 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 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, 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 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 or 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 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 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 proceed 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

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 evaporating 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. 4thly. Evaporation is always increaſed greatly by a current of air flowing over the evaporating ſurface. Hence a calm day is always warmer than one in which there is a ſtrong wind †.

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* See Dr. Franklin's Meteorological Conjectures.

† Kirwan on Climate, c. 1.

From theſe facts, and from what is 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; and Guiana affords a ſtill more remarkable inſtance. Of that country, 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 further obſerved, 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.

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* Philad. Tranſ. vol. ii. p. 150.

From the whole of what has been ſtated, it will follow, that a wet ſummer will generally be ſucceeded 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.

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

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* Derham's Phyſic. Theol. l. i. c. 3.

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.

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 atmo-ſphere.

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* Kirwan on Climate, c. 15.

ſphere. 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 by the antients 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 number 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 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

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* Lampades, faces, bolides, trabes, and chaſma cœli. See Plin. Nat. Hiſt. l. ii, c. 25, 26.

† Plin. Nat. Hiſt. l. ii. c. 25, 26.

‡ Ib. c. 27.

‖ Ib. c. 37.

nearer,

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 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 prodigious effulgence, then it began gradually to grow dim; ſo that, upon its diſappearing behind the intervening mountain, its light was very faint.'

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* Ulloa, vol. i. p. 41.

'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 could not have been leſs than a mile long and half a mile broad *.

Two of theſe meteors appeared in this country in the year 1783, of which a moſt particular and truly philoſophical account, by Dr. Blagden, is publiſhed in the Philoſophical Tranſactions of the following year; and as his deſcription will apply to many phenomena of the kind, I cannot take any better method to eluci-

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* Goldſmith's Hiſt. Earth, Vol. I. p. 382.

date this part of the ſubject, than by preſenting my readers with a ſhort abſtract of this very curious and learned memoir.

The firſt of the two meteors in queſtion was ſeen on the 18th of Auguſt, and was, in appearance, a luminous ball, which roſe in the N. N. W. nearly round; it, however, ſoon became elliptical, and gradually aſſumed a tail as it aſcended, and, in a certain part of its courſe, ſeemed to undergo a remarkable change, compared to burſting; after which it proceeded no longer as an entire maſs, but was apparently divided into a cluſter of balls of different magnitudes, and all carrying or leaving a 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 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 the 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 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 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 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.

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

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* See Chap. V.

ſion the main-topmaſt 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 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

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* 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 excrement of the heron, bittern, or ſome animal of the crane kind, which feed on aquatic animals, and have peculiar organs of digeſtion.

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 matter.

Concerning the nature and compoſition of the *ignis fatuus*, or will-o'-the wiſp, there is leſs diſpute; the generality of philoſophers being agreed that it is cauſed by ſome volatile vapour of the phoſphoric kind, probably the phoſphoric hydrogen gas. The light from putreſcent ſubſtances *, particularly putrid fiſh, and thoſe ſparks emitted from the ſea, or ſea-water when agitated in the dark, correſpond in appearance with this meteor. Sir Iſaac Newton defines the *ignis fatuus* to be " a vapour ſhining without heat;" and it is uſually viſible in damp places, about dunghills, burying grounds, and other ſituations, which are likely to abound with phoſphoric matter.

A remarkable *ignis fatuus* was obſerved by Mr. Derham, in ſome boggy ground, between two rocky hills. He was ſo fortunate as to be able to approach it within two or three yards. It moved with a briſk and deſultory motion about a dead thiſtle, till a ſlight agitation of the air, occaſioned, as he ſuppoſed, by his near approach to it, cauſed it to jump to another place; and as he approached, it kept flying before him. He was near enough to ſatisfy himſelf, that it could not be the ſhining of glow-worms or other inſects—it was one uniform body of light.

M. Beccaria mentions two of theſe luminous appearances, which were frequently obſerved in the neighbourhood of Bologna, and which emitted a light equal to that of an ordinary faggot. Their motions were unequal, ſometimes riſing, and ſometimes ſinking towards the earth; ſometimes totally diſappearing,

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* This ſubject will be more amply treated of in the ſucceeding Book, under the title Phoſphorus, Book VIII.

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 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.

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 decompoſition, ariſes all that variety of weather of which the atmoſphere of all countries, and particularly that of iſlands, is ſo ſuſceptible.

The atmoſphere itſelf is influenced and modified by the variations of its denſity; 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 ſcience of predicting the weather is at preſent vague and imperfect, becauſe it is but lately that accurate obſervations have been made on the changes of the weather, yet from what we may collect from the works of De Luc, De Sauſſure, Marſhall, and Kirwan, we are authorized to expect ſome ſucceſs in thoſe inquiries. But it can hardly be ſuppoſed that their obſervations, in the preſent ſtate of ſcience, will be ſufficient to form a perfect theory, till ſeconded by thoſe of ſucceeding times. For this 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. 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 *.

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* Mem. Royal Iriſh Acad. Vol. v.

II. Among

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 tumult in the air, which is excited by the heat of the ſun. The 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

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† Diſſertation on the Barometer.

‡ See this Book, Chap. IX.

ſometimes from its elaſticity. It has been proved, 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. 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,

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* Briſſon. Vol. i.

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 ſince (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 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 in the winter with a north or eaſt wind, it generally forebodes a froſt.

3. It is neceſſary to attend to the progreſs of the riſe and fall; thus, if it ſinks ſlowly, the rain may be expected to be of ſome continuance. In the ſame manner, when the mercury riſes gradually, we may be inclined to believe, that the fine weather will be laſting.

4. When the barometer is fluctuating, riſing and falling ſuddenly, 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 ſudden, a high wind frequently follows.

7. When an extraordinary fall of the mercury happens, without any remarkable change near at hand, there is ſome probability of a ſtorm at a diſtance.

8. The barometer will deſcend ſometimes as an indication of wind only; nor is its riſe always a certain ſign of fair weather, particularly if the wind is to the north or the eaſt.

9. A north-eaſt wind generally cauſes the barometer in England to riſe, and it is generally loweſt with a ſouth-weſt wind.

If the air in foggy weather becomes hotter by the action of the ſun alone, the fog generally diſſipates, and the air remains ſerene; but if the barometer falls, and the change of temperature is from a ſouth or ſouth-weſt wind, the fog riſes and forms into clouds, and its aſcent is generally a ſign of rain.

"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, particularly when a thunder-ſtorm is near, when ſmall fragments of clouds collect, and in a little time cover the whole face of the ſky.

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

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, or howling wind has been generally eſteemed almoſt an infallible ſign of rain.

Though theſe principles have never as yet been reduced to a regular ſyſtem; yet from obſerving carefully the above prognoſtics, or rather the combinations and coincidences of them, very tolerable conjectures may be formed of the weather which may be expected, particularly with reſpect to drought or moiſture. It is obſervation only, however, which can enable any man to form ſuch conjectures with tolerable accuracy. The knowledge of weather is rather a practical than ſpeculative ſcience; to "diſcern the face of the ſky" was an art poſſeſſed by ruſtics at a very remote period of ſociety; and, at this time, the judgment of a ſhepherd or ploughman on this ſubject will commonly be found a more infallible guide than that of a philoſopher.

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. Jeffries 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 experiment, 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.

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

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 *.

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

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* The principle upon which the aerial machines of Meſſrs, Montgolfier were conſtructed was that of air rarefied by heat, by which it became expanded, and therefore diſpoſed to aſcend in 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.

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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 rarefied 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 eſſential 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 this aerial excurſion.

The firſt balloon was exhibited in England on the 25th of 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 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 parts 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 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. Jefferies, '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.

The art of navigating through the air made ſo rapid a progreſs, that within two years from its firſt diſcovery

very 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 conſiderbly, 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 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.

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 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, 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 extraordinary 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

ments 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.