LETTERS

OF

EULER.

LETTERS

OF

[L.] EULER

ON DIFFERENT SUBJECTS

IN

PHYSICS AND PHILOSOPHY.

ADDRESSED TO

A GERMAN PRINCESS.

TRANSLATED FROM THE FRENCH BY

HENRY HUNTER, D.D.

WITH

ORIGINAL NOTES,

And a Glossary of Foreign and Scientific Terms.

Second Edition.

IN TWO VOLUMES.

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In consequence of the three Volumes of EULER in French being comprized in two, in the Translation, a few inaccuracies have occurred in the numbering of the Plates, which however will be remedied by the Plates being placed opposite the Pages, as above.

PREFACE.

IT was long a matter of ſurprize to me, that a Work ſo well known, and ſo juſtly eſteemed, over the whole European Continent, as EULER's *Letters to a German Princeſs*, ſhould never have made it's way into our Iſland, in the language of the Country. While Peterſburg, Berlin, Paris, nay the capital of every petty German principality, was profiting by the ingenious labours of this amiable man, and acute philoſopher, the name of EULER was a ſound unknown to the ear of youth in the Britiſh metropolis. I was mortified to reflect that the ſpecious and ſeductive productions of a *Rouſſeau*, and the poiſonous effuſions of a *Voltaire*, ſhould be in the hands of ſo many young men, not to ſay young women, to the perverſion of the underſtanding, and the corruption of the moral principle, while the ſimple and uſeful inſtructions of the virtuous EULER were hardly mentioned.

I frequently ſuggeſted the idea of a tranſlation to more than one literary friend, in whoſe ability for the taſk I could place greater confidence than in my own: but not finding it undertaken, I determined, at length, to attempt it myſelf, with the ability which I had; and, in doing this, I conſidered myſelf as rendering a meritorious ſervice to my country.

As ſoon as Providence had beſtowed on me the bleſſing of children, I felt it to be my duty to charge myſelf with their inſtruction. How I have ſucceeded it becomes not me to ſay: but every day I live, the importance of early and proper

proper culture is more deeply impreſſed on my mind. There ſeems to be ſtill a *deſideratum* towards completing the plan of an uſeful education—ſomething that ſhall ſuggeſt to the opening mind, ſuitable ſubjects of thought, and aſſiſt it in purſuing a ſimple train of reflection—ſomething that ſhall convey knowledge in the guiſe of amuſement; that ſhall not be impoſed as a taſk, but conferred as a favour.

The ſubjects of theſe Letters, and the Author's method of treating them, ſeem to me much adapted to this purpoſe. With the aſſiſtance of a very moderate apparatus, they might conduct youth of both ſexes, with equal delight and emolument, to a very competent knowledge of natural philoſophy: very little previous elementary knowledge is neceſſary to a profitable peruſal of them, and that little may be very eaſily acquired.

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A considerable part of our common school education, it is well known, consists of the study of the elegant and amusing poetical fictions of Antiquity, Without meaning to decry this, may I not be permitted to hint, that it might be of importance frequently to recall young minds from an ideal world, and it's ideal inhabitants, to the real world, of which they are a part, and of which it is a shame to be ignorant. Let your pupil, by all means, read the poets; let him read Ovid, and, after he has amused himself with the golden age of old Saturn, lead him out into the open firmament of heaven, and shew him the venerable planet of that name, coeval with time, yet shining with unimpaired lustre, after so many revolutions of ages. Having administered the antidote that may repel the poison, which a display of the lewd intrigues of a fabulous Jupiter or Venus naturally instill; let him view, through the

the telescope, the two beautiful stars so called, emitting their chaste and modest light to the unpolluted eye of sober reason. When he has diverted himself with the transformation of a lady into a bear, and that bear into a constellation, point out to him the heavenly northern light, which never changes it's place, and, with undeviating fidelity, conducts the mariner through the seas of a hemisphere. Let him accompany Phaeton to the palace of the sun, and smile at beholding the adventurous boy mount the flaming chariot; and then check his mirth by pointing to the glorious orb of day, travelling in the greatness of his strength; not dragged round the earth by fiery-footed steeds, but wheeling worlds on worlds, each in his several orbit, around him, with irresistible force.

Why should not the boy be taught the principle on which his kite flies?

What more pleaſant amuſement can he have than to communicate to the needle the magnetic virtue, and to ſteer his courſe through the hazel grove, by a compaſs of his own conſtructing? Why not teach him to elicit the electric ſpark; and to aſtoniſh and delight his ſiſters with the wonders of the magic lantern?

Euler wrote theſe Letters for the inſtruction of a young and ſenſible female, and in the ſame view that they were written, they are tranſlated, namely, the improvement of the female mind; an object of what importance to the world! I rejoice to think I have lived to ſee female education conducted on a more liberal and enlarged plan. I am old enough to remember the time when well-born young women, even of the north, could ſpell their own language but very indifferently, and ſome hardly read it with common decency; when the young lady's hand-writing presented a medley of outlandish characters; and when a column of pounds, shillings and pence presented a labyrinth as inextricable as the extraction of the cube root. While the boys of the family were conversing with Virgil, perhaps with old Homer himself, the poor girls were condemned to cross-stitch, on a piece of gauze-canvass, and to record their own age at the bottom of a sampler.

They are now treated as rational beings, and society is already the better for it. And wherefore should the terms *female* and *philosophy* seem a ridiculous combination? Wherefore preclude to a woman any source of knowledge to which her capacity, and condition in life, entitle her to apply? It is cruel and ungenerous to expose the frivolity of the sex, after reducing it to the necessity of being silly and frivolous. Cultivate a young woman's understanding, and her person will become, even to herself, only a secondary concern; let her time be filled up in the acquisition of attainable and useful knowledge, and then she will cease to be a burden to herself and to every body about her; make her acquainted with the world of nature, and the world of art will delude her no longer.

The time, I trust, is at hand, when the Letters of EULER, or some such book, will be daily on the breakfasting table, in the parlour of every female academy in the kingdom; and when a young woman, while learning the useful arts of pastry and plain-work, may likewise be acquainting herself with the phases of the moon, and the flux and reflux of the tides. And I am persuaded she may thrum on the guitar, or touch the keys of the harpsichord, much more agreeably both to herself and others, by studying

ſtudying a little the theory of ſound. I have put the means of this in her power; it will be at once her fault and her folly if ſhe neglect it.

In tranſlating the Work, I have followed the laſt Paris Edition, given by Meſſrs. *de Condorcet & de la Croix*, in 1787, for the purpoſe of introducing the uſeful notes of theſe gentlemen; but I have taken the liberty to reſtore, from the original edition, that of Mietau and Leipſic, in 1770, ſeveral paſſages which the French Editor had thought proper to ſuppreſs. To ſome notes of my own I have added ſeveral others, furniſhed by two ingenious friends, whoſe names I am not at liberty to publiſh. The courſe of thirty-four years of a ſcientific age, muſt have ſupplied abundance of new facts and experiments, by which the philoſophy of even a EULER may be corrected and improved. The tranſlated notes of the Paris Edition, I have, for the ſake of diſtinction, marked with the characters *F. E.* and the original notes of this Edition, with the initials *E. E.* And I think it my duty, in this place, to vindicate to our ingenious countryman, Mr. *Dollond*, the optician, the diſcovery of achromatic glaſſes for teleſcopes, mentioned in the letters on dioptrics; for that gentleman is, in truth, the Author of this valuable improvement.

I have had the illuſtrative plates engraved in a better ſtyle and manner than French artiſts generally employ on mathematical figures: and to do credit to myſelf, not to ſay EULER, he appears in his Engliſh dreſs with every advantage which the ſtationer and printer could beſtow. At the ſame time, in order to keep down the price as much as poſſible, inſtead of dividing the Work into

Three

Three Volumes, as in all the foreign editions, I have reduced mine to *Two*; as the division is altogether indifferent to the subjects.

It being generally acceptable to the Reader to know something about the *man* with whom he is conversing as an *author*; to gratify this curiosity, I have likewise given a translation of the *Elogium of* EULER, read before the Academy of Sciences, and prefixed to M. de *Condorcet's* edition, because it contains some interesting traits of the character and events of the life of this distinguished personage. But what is the life of a literary or scientific man, and where are we to find the history of it? In his works. NEWTON and EULER are their own best biographers; and the library of every scholar in Europe exhibits a never-dying representation of what they were, and what they atchieved. We have hardly a trace of *Wren's* perſonal and domeſtic habits; but every ſtone of St. Stephen's Walbrook, and of St. Paul's, is inſcribed with his name, and tranſmits a memoir of the Architect.

The frequent, tireſome, courtly addreſs of Your Highness, except at the firſt ſetting out, I have entirely omitted; out of no diſreſpect to Princes, but becauſe it ſeemed to me a mere unneceſſary waſte of words, which only encumber and disfigure a work of ſcience. The Princeſs and her inſtructor are both gone to that awful world, in which the diſtinctions of the preſent, thoſe of virtue excepted, are for ever obliterated.

As every book ſhould be as complete in itſelf as poſſible, and this being deſtined to the uſe of the unlearned, I have ſubjoined a gloſſary of the foreign and ſcientific words which occur in the courſe of of theſe Letters. Some will, perhaps, think I may have ſwelled this beyond the neceſſary ſize, and given an explanation of many terms already ſufficiently underſtood. If this be an error, it is on the ſafe ſide. I would rather inſert twenty words of this deſcription, than omit one with which an ordinary reader might be unacquainted, and his progreſs thereby retarded. And I well know, that there is often a vague and obſcure idea of words floating in the brain, which a ſhort deſcription or an example would inſtantly render preciſe and diſtinct: and many young perſons would, without heſitation, conſult a gloſſary, who might be afraid, or aſhamed, or, perhaps, too proud, to aſk a queſtion.

H. H.

Hoxton, 1802.

ADVERTISEMENT.

BY THE FRENCH EDITOR.

THE Letters of EULER to a German Princeſs have acquired, over all Europe, a celebrity, to which the reputation of the Author, the choice and importance of the ſeveral ſubjects, and the clearneſs of elucidation, juſtly entitle them. They have deſervedly been conſidered as a treaſury of ſcience, adapted to the purpoſes of every common ſeminary of learning. They may be ſtudied to advantage without much previous elementary knowledge; they convey accurate ideas reſpecting a variety of objects, highly intereſting in themſelves, or calculated to excite a laudable curioſity; they inſpire a proper taſte for the ſciences, and for that ſound philoſophy which, ſupported by ſcience, and never loſing ſight of her cautious, ſteady, methodical advances, runs no riſk of perplexing, or miſleading the attentive ſtudent.

The only cenſure that can be paſſed on theſe Letters is, now and then, a digreſſive detail, ſomewhat

ſomewhat too tedious, on queſtions rather foreign to the ſciences, and conſiderable inaccuracy in point of ſtyle. Without failing in the reſpect due to EULER, I thought myſelf at liberty to omit ſome paſſages altogether, and to correct the ſtyle of others. Few Readers, ſurely, will be ſo faſtidious as to refuſe the admiration attached to the name of this illuſtrious man, for the ſake of ſome ſlight blemiſhes, in a work of ſuch conſiderable length. A genius, like his, which has ſignalized itſelf by ſo many important diſcoveries, can ſuffer no diminution of greatneſs, from his not having written a foreign language with claſſical purity. A man whoſe tranſcendant powers have aſtoniſhed and confounded even thoſe whom habits of profound reflection muſt have rendered hard to pleaſe, reſpecting prodigies of this ſort, is not leſs worthy of veneration, that he did not apply the whole force of his mind to every object which preſented itſelf. It is of the laſt indifference to his glory, whether theſe ſmall ſpecks are effaced, or ſuffered to remain.

But the caſe is widely different as to the perſons for whoſe uſe the peruſal of this work is particularly deſigned. It is of importance for young people, whether of France, or of any other country, to defer reading till they thoroughly underſtand the language of books, in which the

rules

rules of that language may be frequently violated. And the youth of the French nation must be cautioned against turning into ridicule a few uncouth expressions which, in the hurry of composition, may have dropped from the pen of a man of genius. Respect for every thing which merits this appellation is one of the sentiments which education ought most powerfully to inculcate, as it is one of the most infallible preservatives against prejudice of every kind, against the illusions of vanity and self-love, nay, against the passions which deprive us of the force necessary to our approximation toward these objects of universal admiration.

As to other retrenchments, they affect, almost all of them, reflections which relate less to the sciences and philosophy, than to theology, and frequently even to the peculiar doctrines of that ecclesiastical communion in which EULER lived. It is unnecessary to assign a reason for omissions of this description.

I have prefixed to this edition the Elogium of EULER, read before the Academy of Sciences, omitting only some scientific details, which might have appeared tedious to certain Readers.

As the Letters of EULER contain nothing, on several questions, capable of interesting the generality of mankind, I have made some additions, but

ELOGIUM OF EULER.

LEONARD EULER, Prefident of the Mathematical School, in the Academy of Peterfburg, and previoufly in that of Berlin; Fellow of the Royal Society in London; and of the Academies of Turin, Lifbon and Bâle; Foreign Affociate of that of the Sciences, was born at Bâle, April the 15th, 1707, being the fon of *Paul Euler* and *Margaret Brucker*.

His father who, in 1708, undertook the paftoral charge of the village of Riechen, in the vicinity of Bâle, was his firft inftructor; and he enjoyed betimes the pleafure of contemplating the progrefs of his fon's expanding faculties, and dawning glory, a cordial fo reviving to the heart of a parent, advance under his own eye, and gather ftrength from his own affiduities.

He had ftudied mathematics under *James Bernouilli*. It is well known, that this celebrated fcholar united to a great genius for the fciences, a profound philofophy, which is not always the companion of this genius, but which ferves to give it a wider range, and to render it's exertions more ufeful. In teaching, he endeavoured to imprefs on his pupils, that geometry is not a detached fcience, but exhibited it to them as, at once, the bafis and the key-ftone of all human knowledge; as the ſcience in which the progreſs of the mind may be the moſt diſtinctly obſerved; the ſcience, the cultivation of which exerciſes our faculties to the greateſt advantage, as giving to the underſtanding, at one and the ſame time, ſtrength and accuracy; finally, as a ſtudy equally valuable, from the number and the variety of it's applications, and from it's tendency to inure the ſtudent to a method of reaſoning, which may, afterwards, be ſucceſsfully employed, in the inveſtigation of every ſpecies of truth, and as a guide in the conduct of life.

Paul Euler, who had fully imbibed the principles of his maſter, inſtructed his ſon in the elements of mathematics, though he had deſtined him, ultimately, to the ſtudy of theology; and ſuch was young EULER's early proficiency, that on being ſent to the univerſity of Bâle, he was deemed not unworthy of the attention and particular inſtructions of *John Bernouilli*. Such was his application, and ſuch his happy diſpoſitions, as quickly to ſecure to him the friendſhip of *Daniel* and *Nicolas Bernouilli*, the pupils, and, by this time, the rivals of their father. Nay, he had the felicity of getting into the good graces of the ſevere *John Bernouilli* himſelf, who carried his condeſcenſion ſo far as to give him a private leſſon, once a week, in the view of removing any difficulties which might occur in the courſe of reading and ſtudy. EULER employed the other days of the week in ſuch a manner as would enable him to make the moſt of this diſtinguiſhed mark of favour.

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This excellent method of profecuting his ftudies, preferved opening genius from exhaufting it's ftrength, in combating infuperable difficulties, and from wandering in unknown mazes, which it might attempt to unravel: it directed and feconded his own exertions; but, at the fame time, laid him under the neceffity of calling forth all his powers, which, accordingly, received conftant increafe from an exercife proportioned to his age, and to the progrefs in knowledge which he had already made.

But of this fingular advantage he was foon deprived; for fcarcely had he attained the degree of Mafter of Arts, when his father, who intended him for his own fucceffor, enjoined him to exchange the ftudy of mathematics for that of theology. Happily, the effect of this act of authority was of fhort duration. It proved no difficult matter to perfuade the father, that his fon was deftined to fupply, to the learned world, the place of *John Bernouilli*, and not to fink into the obfcure parfon of Riechen.

An effay, compofed by EULER in his nineteenth year, on the mafting of fhips, a fubject propofed by the Academy of Sciences, procured him, in 1727, an addition to his academical honours, fo much the more refpectable, that the youthful native of the Alps could have derived no affiftance from practical knowledge, and that he yielded the palm to Mr. *Bouguer* alone, an able geometrician, then at the zenith of his reputation, and, for ten years before, profeffor of hydrography in a maritime city.

About the fame period, EULER ftood candidate

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for a vacant chair in the univerſity of Bâle: but it is fate, or chance, that ſettles the diſpute between competitors for offices of this ſort, and, on this occaſion, it was unfavourable, I do not ſay to EULER, but to his country, which, a few days afterward, loſt him for ever.

Two years before this, *Daniel* and *Nicolas Bernouilli* had been invited to Ruſſia. EULER felt the ſincereſt regret at parting with the friends of his youth, and engaged them to promiſe their utmoſt exertions to procure him a ſimilar invitation, which he was eager to participate. This needs to excite no ſurprize. The ſplendor of the capital of a vaſt empire, the glare diffuſing itſelf over the purſuits of which it is the theatre, and over the very perſons of it's inhabitants, ſeems to confer a glory on them, capable of eaſily ſeducing a youthful imagination, and of dazzling the free, but poor and obſcure, citizen of a petty republic.

The brothers, *Bernouilli*, were conſcientiouſly faithful to their promiſe, and exerted themſelves as ſtrenuouſly, to bring forward a competitor ſo formidable, as ordinary men would have done to keep a rival out of ſight.

EULER's journey to Ruſſia commenced under auſpices the moſt melancholy and diſcouraging. It was not long before he received intelligence, that *Nicolas Bernouilli* had fallen a victim to the ſeverity of the climate; and the very day he ſet foot on Ruſſian ground, Catharine I. paid the debt of nature. ...ent, at firſt, ſeemed to threaten the approaching

ing dissolution of the Academy, whose establishment that Princess had just completed, in compliance with the will of the deceased Czar, her husband.

EULER, at a prodigious distance from his native country, destitute of the advantage which *Daniel Bernouilli* possessed, that of an illustrious and respected name, to prepare his way, formed the resolution of entering into the Russian marine service. One of the admirals of Peter I. had already promised to procure him a situation; when, happily for geometry, the storm, which lowered over the sciences, spent itself. *Daniel Bernouilli* retired to his own country: EULER was declared Professor of Geometry, and successor to his illustrious friend, in 1733. The same year he married a young lady of the name of *Gsell*, a compatriot of his own, the daughter of a painter, whom Peter I. had brought with him to Russia, on returning from his first voyage.

From this time forward, to use *Bacon*'s expression, EULER felt that he had given hostages to fortune: and that the country, in which he could hope to form an establishment for his family, was necessarily transformed into his native country. Born and educated in the bosom of a nation, all whose governments preserve, at least, the appearance and the language of a republican constitution; in which, notwithstanding distinctions more real, than those which separate between the highest slave of a despot and the lowest of his subjects, the forms of equality have always been scrupulously observed; in which the respect due to the laws extends to usages the most indifferent, proand humane. At that period he went from Peterſburg to Berlin, on the earneſt ſolicitation of the King of Pruſſia. He was preſented to the Queen-mother. This Princeſs took great pleaſure in the converſation of enlightened men: ſhe received them with that noble familiarity which announces, in Princes, the ſentiment of a perſonal greatneſs, independent of rank and title, and which has become one of the characteriſtic marks of that auguſt family. The Queen of Pruſſia, however, could extract from EULER monoſyllables only: ſhe taxed him with a timidity and reſerve, which the cordiality of his reception could not poſſibly have inſpired: *Why, then, will you not talk to me*, ſaid the Queen? *Becauſe Madam*, replied he, *I have juſt come from a country, where people are hanged, if they talk.*

Feeling myſelf now called upon to give ſome account of EULER's immenſe ſcientific labours, I ſhrink from the impoſſibility of following him in detail, of conveying any thing like an accurate idea of that multiplicity of diſcoveries, of new methods of inveſtigation, of ingenious views, diffuſed over more than thirty ſeparate publications, and over near ſeven hundred memoirs, of which about two hundred, depoſited in the Academy of Peterſburg previous to his death, are deſtined to enrich, in their order, the future collections publiſhed by that learned body.

But a particular character ſeems, to me, to diſtinguiſh EULER from the other illuſtrious men who, in purſuing the ſame career, have attained a glory which his has not eclipſed; that character is, his having

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embraced the mathematical ſciences in their univerſality; his having brought to perfection, one after another, the different parts; and, enriching the whole by important diſcoveries, his having produced a very beneficial revolution in the manner of treating them. I imagined, therefore, that in ſketching a methodical repreſentation of the different branches of theſe ſciences, in pointing out the progreſs of each, and the happy improvements to be aſcribed to the genius of EULER, I ſhould give, at leaſt as far as my ability permits, a juſter idea of this wonderful man, who, by uniting ſo many extraordinary talents, has preſented a phenomenon, if the expreſſion may be allowed, of which the hiſtory of ſcience has hitherto furniſhed no example.

Algebra had long been a ſcience of very limited uſe and application. The mode of conſidering the idea of magnitude, only in the higheſt degree of abſtraction of which the human mind is ſuſceptible; it's rigorouſly ſeparating from that idea every thing which, by employing imagination, might give ſupport, or repoſe, to the underſtanding; finally, the extreme generality of the ſigns which this ſcience makes uſe of, render it in ſome meaſure too foreign to our nature, too remote from ordinary conception, to admit of the mind's taking extraordinary pleaſure in it, and of eaſily acquiring a habit of tracing it's operations. The algebraic method is apt to diſcourage even perſons the moſt diſpoſed to abſtract ſpeculation. If the object of purſuit be ever ſo little complicated, we are forced to loſe ſight of it entirely,

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and to confine our whole attention to dry algebraic characters; the road is ſafe and ſure, but the point which is aimed at, and that from whence we took our departure, equally vaniſh from the eye of the geometrician; and it required no ſlight degree of courage, to venture out of ſight of land, without any other pilot than a recently diſcovered ſcience. Accordingly, on examining the works of the great geometricians of the laſt age, even of thoſe to whom algebra is indebted for the moſt important diſcoveries, we ſhall ſee how little they were accuſtomed to handle this very weapon, which has been brought to ſuch a ſtate of perfection; and it is impoſſible to refuſe to EULER the praiſe of having effected a revolution, which renders algebraic analyſis a mode of calculation luminous, univerſal, of general application and of eaſy acquiſition.

Thus, at certain epochs, when after ſtrenuous exertions the mathematical ſciences ſeemed to have exhauſted all the reſources of genius, and to have reached the *ne plus ultra* of their career; all at once a new method of calculation is introduced, and the face of the ſcience is totally changed. We find it immediately, and with inconceivable rapidity, enriching the ſphere of knowledge, by a ſolution of an incredible number of important problems, which geometricians had not dared to attempt, intimidated by the difficulty, not to ſay the phyſical impoſſibility, of purſuing calculation to a real iſſue. Juſtice would, perhaps, demand, in favour of the man who invented

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ourfelves to fome detached parts, in preference; in proportion as fucceffive difcoveries multiply, the relations which unite the parts gradually appear; and to the illumination refulting from this union, we are moft frequently indebted for the great difcoveries, which form an era in the hiftory of the human mind.

I fhall conclude this brief reprefentation of EULER's labours, on pure analyfis, with obferving, that it would be injuft to limit it's influence on the progrefs of mathematics, to the innumerable difcoveries with which his works abound. The communications which he has opened between all the parts of a fcience fo extenfive; thofe general views which fometimes he does not fo much as indicate, but which cannot efcape an attentive obferver; the paths, whofe entrance he has fatisfied himfelf with clearing by removing the firft obftacles which oppofed; thefe are fo many more benefits conferred on the fphere of fcience, and of which pofterity will undoubtedly avail itfelf, while perhaps the hand which beftowed them may be forgotten.

The treatife on mechanics, which EULER gave to the world in 1736, is the firft great work in which analyfis has been applied to the fcience of motion. The number of things, entirely new, or exhibited in a new light, which this book contains, would have aftonifhed geometricians, had not EULER already publifhed, feparately, the greateft part of it.

In his endlefs labours on the fame fcience, he was ever faithful to analyfis, and the happy ufe he made

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He treated, in all it's extent, the naval ſcience; in an elaborate work, to which an intelligent analyſis ſerves as baſis, and in which queſtions of the greateſt difficulty are ſubjected to this general and fertile method, which he underſtood ſo well to create and to employ. He publiſhed, many years afterward, on the ſame ſubject, an elementary abridgment of this treatiſe, containing, under the ſimpleſt form, every thing uſeful in practice, and neceſſary to be known by perſons who devote themſelves to the marine ſervice. This work, though deſigned by the Author merely for the ſchools of the Ruſſian empire, procured for him a liberal gratification from the King of France, who judged, that labours beneficial to mankind demanded the grateful acknowledgments of all Sovereigns, and who wiſhed to demonſtrate to Europe, from one extremity to another, that talents ſo rare could neither be overlooked, nor remain unrewarded. EULER was abundantly ſenſible of the value of this mark of reſpect from a great Prince; and it derived an additional charm, in his eyes, from the hand through which it was tranſmitted, that of Mr. *Turgot*, a miniſter univerſally reſpected for his talents and for his virtues; a man formed for commanding opinion, rather than following it, and whoſe ſuffrage, ever dictated by truth, and never by the deſire of attracting to himſelf the applauſe of the public, might be an acceptable piece of flattery, even to a wiſe man, too much accuſtomed to glory to be ſtill awake to the voice of fame.

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In men of a ſuperior genius, extreme ſimplicity of character may eaſily conſiſt with thoſe qualities of mind, which moſt forcibly announce ability and delicacy of feeling. EULER, accordingly, notwithſtanding that ſimplicity which never forſook him, knew, however, to diſtinguiſh with a ſagacity, always indulgent it is true, the homage of enlightened admiration from that which vanity laviſhes on great men; to ſecure to itſelf at leaſt the merit of enthuſiaſm.

His dioptrical reſearches are founded on an analyſis leſs profound, and we are tempted to give him credit for it, as being a kind of ſacrifice. The different rays of which a ſolar ray is formed, ſubſiſt in the ſame medium of different refractions; ſeparated thus from adjacent rays, they appear ſingle, or leſs blended, and give the ſenſation of the colour proper to them. This refrangibility varies in different mediums for every ray, and in conformity to a law which is not the ſame with that of the mean refraction in theſe mediums. This obſervation ſuggeſted a belief, that two unequal priſms, and of different ſubſtances, combined, might divert a ray from it's direction, without decompounding it, or rather by replacing the elementary rays, by refraction, in a parallel direction. On the truth of this conjecture might depend, in teleſcopes, the deſtruction of the iris, which colours objects viewed through lenticular glaſſes. EULER was convinced of the poſſibility of ſucceſs, conformably to this metaphyſical idea, that,

he eye is compoſed of different humours, it is only in

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the view of destroying the effect of the aberration of refrangibility. The only thing requisite, therefore, was an attempt to imitate the operation of nature, and he proposed the means of execution according to a theory which he had formed. His first essays induced naturalists to attend to an object which they seemed to have neglected. Their experiments did not correspond to EULER's theory, but they confirmed the views he entertained respecting the perfection of telescopes. And, instructed by these, in the laws of dispersion, in different mediums, he abandoned his first ideas, subjected to calculation the result of their experiments, and enriched dioptrics with analytical formules, simple, commodious, general, and applicable to instruments of every possible construction.

We have, besides, some essays of EULER, on the general theory of light, the phenomena of which he endeavoured to reconcile with the laws of the oscillations of a fluid; because the hypothesis of the emission of rays in a straight line, appeared to him to present insurmountable difficulties. The theory of the loadstone, that of the propagation of fire, the laws of the cohesion of bodies, and those of friction, furnished him, likewise, with subjects of ingenious calculations, but, unfortunately, supported by hypothesis, rather than by experiment.

The calculation of probabilities and political arithmetic were farther objects of his indefatigable application. I shall here only mention his researches

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on bills of mortality, and the means of deducing them from phenomena with greater exactneſs; his method of ſtriking a medium from the obſervations made; his calculations reſpecting the eſtabliſhment of a reverſionary fund, in the view of ſecuring to widows, or orphans, either a fixed ſum, or an annual revenue, payable after the death of a huſband or father; an ingenious and humane method, deviſed by philoſophic geometricians to counterbalance the moral evil reſulting from the ſettlement of life-annuities, and to convert, to the relief of families, the ſmalleſt ſavings from the principal's daily earnings, or from the revenue of a commiſſion, a place or a penſion.

We have ſeen in the elogium of *Daniel Bernouilli*, that he had divided with EULER alone the glory of having carried off thirteen prizes, propoſed by the Academy of Sciences: They often contended for the ſame object, and occupied the ſame ground: and the honour of triumph over a competitor was likewiſe divided between them; but this rivalſhip never encroached on the expreſſions of reciprocal eſteem, r cooled the ardor of mutual friendſhip. On examining the ſubjects for which the one or the other tained the victory, we find that ſucceſs depended incipally on the character of talent peculiar to each. When the queſtion required addreſs in the manner of taking it up, a dexterous application of experiment, or new and ingenious phyſical views, *rnouilli* had the advantage: but did it preſent

ſent difficulties, which profound and accurate calculation could reſolve; was it neceſſary to create a new method of analyſis, victory declared for EULER. Were any one ſo preſumptuous as pretend to judge between them, he would find that he had to pronounce, not between two men, but between minds of a different genius, between two methods of employing genius.

I ſhould have conveyed but a very imperfect idea of EULER's fertility of invention, unleſs I added to this faint ſketch of his labours, that there are very few ſubjects of importance, once treated by him, that he did not retrace; nay, ſo far as to recompoſe his firſt work ſeveral times over. Sometimes he ſubſtituted a direct and analytical method, in place of one more indirect: ſometimes he extended his firſt ſolution to caſes which had at firſt eſcaped him; adding almoſt always new examples, which he knew how to ſelect with ſingular ſkill among thoſe which preſented, or ſome uſeful obſervation, or curious remark.

The intention merely of giving to one of his productions a form more methodical, of rendering it ſomewhat more luminous, of beſtowing on it a higher degree of ſimplicity was to him motive ſufficient for engaging in labours incredible. Never did geometrician write ſo much, and no one ever carried his works to ſuch a height of perfection. When he publiſhed a memoir on a new ſubject, he ſimply explained the track which he purſued; he pointed out to his pupils it's intricacies and aberrations, and having, with ſcrupulous exactneſs, made them accompany the progreſs of his own mind, in his firſt eſſays, he ſhewed them afterwards how he had been enabled to trace a ſimpler path. It is evident, that he preferred the inſtruction of his diſciples to the ſilly ſatisfaction of dazzling them by his own ſuperiority; and that he did not believe he had done enough for ſcience, unleſs he added, to the new truths with which he was enriching it, a candid expoſition of the ideas which led to diſcovery.

On reading the life of a great man, whether it be a conviction of the imperfection attached to frail humanity; whether it be, that the juſtice of which we are capable, does not riſe ſo high as to induce us to acknowledge a ſuperiority for which nothing can be an adequate compenſation; or, finally, whether it be, that the idea of perfection in another mortifies or humbles us ſtill more than that of his greatneſs, but ſome how or another it ſeems neceſſary for us to find out ſome weak part; we hunt after the diſcovery of a defect in him, which may reconcile us to ourſelves; and we are involuntarily diſpoſed to call in queſtion the impartiality of the Biographer, unleſs he points out the weak part, unleſs he withdraws the impertinent veil which conceals the defect.

Euler ſometimes appeared to be taken up with the mere pleaſure of calculation, and to conſider the point of mechanics, or phyſics, which he was examining, only as an occaſion of exerciſing his genius, and

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of following the bent of his reigning paſſion. Some of the learned have accordingly accuſed him of laviſhing his talent for calculation on phyſical hypotheſes, or even on metaphyſical principles, of which he had not ſufficiently examined either the probability or the ſolidity. He has likewiſe been accuſed of depending too much on the reſources of calculation, and of having neglected thoſe with which he might have been ſupplied, by the examination of the very queſtions which he propoſed to reſolve.

We muſt admit, that the firſt of theſe charges is not altogether deſtitute of foundation. In EULER, undoubtedly, the metaphyſician, or even the naturaliſt was not ſo great as the geometrician; and we are conſtrained to regret, that in many parts of his works, thoſe, for inſtance, which he compoſed on the naval ſcience, on artillery, have been of little uſe, except to the progreſs of the ſcience of calculation.

But the ſecond charge appears by no means ſo well founded. We obſerve uniformly, through all the works of EULER, an unremitting effort to add to the riches of analyſis, to extend, and to multiply the applications of it: at the ſame time that it appears to be his only inſtrument, we ſee clearly that it is his wiſh to make it univerſally ſo. The natural progreſs of the mathematical ſciences muſt have, in time, brought about this revolution; but he ſaw it, if I may ſay ſo, completed under his own eye: to his genius we are indebted for it; and it has been the reward of all his exertions and diſcoveries. Accordingly, even when he appears to be miſapplying analyſis, and exhauſting all it's ſecret ſtores in reſolving a queſtion, of which a few reflections, foreign to calculation, would have given him an eaſy and ſimple ſolution, he was frequently only aiming at a demonſtration of the power and reſources of his art; and he merits forgiveneſs at leaſt, if ſometimes, while he ſeemed taken up with another ſcience, it was ſtill to the progreſs and propagation of analyſis that his attention was devoted; and the revolution which this has effected in the world of ſcience, is one of his firſt claims on the gratitude of mankind, and the faireſt title to glory.

I thought myſelf obliged not to interrupt the detail of *Euler*'s ſcientific purſuits, by a recital of the few and ſimple events of his life.

He ſettled at Berlin in 1741, and remained there till 1766.

The Princeſs *d'Anhalt Deſſau*, niece to Frederick II. King of Pruſſia, was deſirous of receiving from him ſome leſſons in natural philoſophy. Theſe leſſons have been publiſhed, under the title of LETTERS TO GERMAN PRINCESS, a work ineſtimable for the [illegible]ularly clear light in which he has diſplayed the [illegible]ſt important truths of mechanics, of phyſical-aſtro[illegible]my, of optics, and of the theory of ſound; and [illegible] the ingenious views, leſs philoſophical but more [illegible]e, than thoſe which have made *Fontenelle*'s Plu[illegible]ity of Worlds outlive the Syſtem of Vortices.

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The name of EULER, ſo great in the ſphere of ſcience; the reſpectful idea attached to his works, employed in unfolding all that is intricate and abſtract in analyſis, diffuſe a ſingular charm over theſe letters, ſo ſimple, and ſo eaſy. Thoſe who have not ſtudied mathematics, aſtoniſhed, perhaps flattered, at being able to underſtand a work of EULER, will feel grateful to him for having deſcended to their level; and theſe elementary details of the ſciences acquire a ſpecies of greatneſs, from their approximation to the glory, and the genius, of the illuſtrious man who traced them.

The King of Pruſſia employed EULER in calculations reſpecting the coinage; on conſtructing the aqueduct of Sans-Soucis; on the formation of ſeveral navigable canals. That great Prince had a mind too enlarged to believe that extraordinary talents, and profound knowledge, ever could be uſeleſs or dangerous qualities; and the felicity of being able to do good, an advantage reſerved by nature for ignorance and mediocrity.

In 1750, EULER made a journey to Frankfort, to receive his mother, then a widow, and to conduct her to Berlin. He had the happineſs to preſerve her till 1761. For eleven years, then, ſhe enjoyed the glory of her highly diſtinguiſhed ſon, in the way that the maternal heart knows how to enjoy, and was ſtill more happy, perhaps, in the tender and aſſiduous expreſſions of filial affection, the value of which that glory greatly enhanced.

During his residence at Berlin, EULER, united to Mr. *de Maupertuis* by the ties of gratitude, thought himself obliged to defend the principle of *the least action*, on which the President of the academy of Prussia had founded the hope of a reputation so exalted. The means which EULER thought proper to use could hardly have been employed by any other person but himself; it was to resolve, on this principle, several of the principal and most difficult problems of mechanics. Thus, in the age of fable, the Gods vouchsafed to forge, for their favourite warriors, armour impenetrable by all the blows of their enemies. It were to have been wished, that Euler's gratitude had confined itself to a protection so noble, and so worthy of himself; but it cannot be denied, that there is an infusion of asperity, rather too strong, in his replies to *Kœnig*; and with sorrow we are constrained to recognize a great man, among the enemies of an unfortunate and persecuted scholar. Happily for EULER, the whole tenor of his life shelters him from a more serious suspicion. But for that simplicity, that indifference to the voice of fame, which he uniformly manifested, it might have been suspected, that the pleasantries of an illustrious partisan of *Kœnig* (pleasantries which *Voltaire* himself has justly consigned to oblivion) had somewhat soured the temper of the gentle and sage geometrician; but if on this occasion he is chargeable with a fault, it must be imputed solely to an excess of gratitude; nd if once in his life he acted wrong, the motive least is respectable.

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The Ruſſian forces having, in 1760, penetrated into the marches of Brandeburg, plundered a farm of EULER's, near Charlottenburg: but General *Tottleben* had not come to make war on the ſciences. Being informed of the loſs which EULER had ſuſtained, he haſtened to repair it, by ordering payment far beyond the real value of the property, and having communicated to the Empreſs *Elizabeth*, an account of this involuntary diſreſpect, ſhe was pleaſed to add a gratuity of four thouſand florins to an indemnification already more than ſufficient. This anecdote is not ſo generally known as it deſerves to be, while we quote, with enthuſiaſtic admiration, ſimilar actions tranſmitted to us from antiquity. Is not this difference in the judgments we form, a proof of the happy progreſs of the human ſpecies, which certain authors ſtill obſtinately perſevere in denying, apparently to ſhun the imputation of having contributed to it?

The government of Ruſſia had never treated EULER as a ſtranger. Notwithſtanding his abſence, part of his ſalary was always regularly paid; and in 1766, the Empreſs having given him an invitation to return to Peterſburg, he complied.

In 1735, the exertion occaſioned by an aſtronomical calculation, for which other academicians demanded ſeveral months, but completed by him in a few days, brought on an indiſpoſition, which iſſued in the loſs of one of his eyes. He had reaſon to apprehend a total loſs of ſight, if he continued to expose himself in a climate, the influence of which was unfavourable to his constitution. The interest of his family got the better of this apprehension; and if we reflect that, to EULER, study was an exclusive passion, we shall readily conclude, that few examples of paternal tenderness have more completely demonstrated, that it is the most powerful, and the sweetest of all our affections.

A few years after, he was overtaken by the calamity which he foresaw and dreaded: but happily for himself, and for the sciences, he preserved still the faculty of distinguishing large characters traced on a slate with chalk. His sons, his pupils, copied his calculations; wrote, as he dictated, the rest of his memoirs; and if we may form a judgment of these from their number, and frequently from the genius transfused through them, it will appear abundantly credible, that from the absence still more absolute of all distraction, and from the new energy which this constrained recollection gave to all his faculties, he gained more, both as to facility and means of labour, than he lost by a diminution of sight.

Besides, EULER, by the nature of his genius and his habits of life, had even involuntarily laid up for himself extraordinary supplies. On examining those great analytical formules, so rare before his time, but so frequent in his works, the combination and display of which unite so much simplicity and elegance, whose very form pleases the eye as well as the mind, it will be evident, that they are not the result fult of a calcalation traced on paper, but that, produced entirely in the head, they are the creation of an imagination equally vigorous and active.

There exift in analyfis, and EULER greatly multiplied their number, formules of a common and almoft daily application; he had them always prefent to his mind, knew them by heart, repeated them in converfation; and Mr. *d'Alembert*, when he faw him at Berlin, was aftonifhed at an effort of memory, which demonftrated, that EULER poffeffed at once a ftrength and a clearnefs of recollection almoft incredible. At length his facility of calculation by the head was carried to fuch a degree as would exceed all belief, had not the hiftory of his labours accuftomed us to prodigies. He has been known, in the view of exercifing his little grandfon in the extraction of the fquare and cube roots, to have formed to himfelf the table of the fix firft powers of all numbers from 1 to 100, and to have preferved it exactly in his memory. Two of his pupils had calculated as far as to the feventeenth term of a convergent feries, abundantly complicated; their refults, though formed after a written calculation, differed one unit at the fiftieth figure: they communicated this difference to their mafter: EULER went over the whole calculation in his head, and his decifion was found to be the true one.

From the time he loft his fight, his chief amufement was to make artificial magnets, and to give leffons in the mathematics to one of his grand-chil-

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dren, who feemed to have a promifing difpofition to that fcience.

He made a point of ftill going occafionally to the Academy, efpecially if delicate circumftances demanded his attendance, or when he deemed his prefence neceffary to the maintenance of liberty. It is eafy to conceive how much it is in the power of a perpetual prefident, appointed by the court, to difturb the peace of an Academy, and how much fuch a feminary has to apprehend from one who, not being elected from their own number, does not feel himfelf reftrained even by a fenfe of that fupport which his reputation needs from the fuffrages of his colleagues. How is it poffible for men, employed folely in calm literary purfuits, and underftanding no language but that of the fciences, to defend themfelves in fuch a cafe; efpecially if ftrangers, unconnected, far from their country, they derive their whole fupport from that government, to which they would appeal for juftice againft an imperious prefident, whom that very government had placed over them.

But there is a degree of glory, which places a man beyond the reach of fear: it is, when all Europe would roufe itfelf to refent a perfonal injury offered to a great man, that he can without rifk oppofe to injuftice the authority of his reputation, and elevate, in fupport of the fciences, a voice which will make itfelf heard. EULER, gentle, modeft as he was, was fenfible of his power, and oftener than once made a very happy ufe of it.

In 1771, the city of Peterſburg ſuffered ſeverely from a terrible conflagration: the flames had caught the houſe of EULER. One *Peter Grimm*, a native of Bâle, whoſe name well deſerves to be tranſmitted to poſterity, apprized of the danger of his illuſtrious compatriot, now blind and enfeebled, burſt through the midſt of the fire, reaches his apartment, places him on his ſhoulders, and ſaves EULER's life, at the hazard of his own. His library, his furniture was deſtroyed, but the zeal and exertions of Count *Orloff* preſerved his manuſcripts. The attention paid to this, at the height of a calamity ſo dreadful, is the moſt honourable and flattering homage which public authority could have offered to ſcience. The houſe of EULER was one of the Empreſs's gifts to him; a ſimilar act of munificence ſpeedily repaired the loſs.

He had by his firſt wife thirteen children, eight of whom died young. His three ſons ſurvived him, but he had the misfortune to loſe both his daughters, the laſt year of his own life. Of thirty-eight grandchildren, twenty-ſix were living at the time of his death. In 1776 he entered a ſecond time into the married ſtate, by eſpouſing a Miſs *Gſell*, ſiſter to his firſt wife's father. He had always retained all that ſimplicity of manners, of which his father's houſe had ſet the example. As long as his ſight remained, he every evening collected, to domeſtic devotion, his grand-children, his domeſtics, and ſuch of his pupils as lodged in the houſe; he read to them a portion of of Scripture, and sometimes accompanied it with an exposition.

He was of a very religious turn of mind. He published a new demonstration of the existence of God, and of the spirituality of the soul: this last treatise has been admitted as a standard book into several colleges of divinity. With scrupulous exactness he adhered to the religion of his country, which is rigid Calvinism: and it does not appear that, after the example of most scholars of the protestant persuasion, he ever took the liberty of adopting peculiar ideas, or of forming a system of religion for himself.

His erudition was very extensive, especially in the history of mathematics. It is alleged that he had carried his curiosity so far as to acquire the knowledge of the processes and rules of astrology; and that he had even made some applications of them. However, when in 1740 he was commanded to calculate the nativity of Prince *Ivan*, he excused himself, by representing that this was the proper business of Mr. *Kraaff*, in quality of royal astronomer. Credulity of this sort, which we are astonished to find at so recent a period in the Court of Russia, prevailed, the age before, in all the Courts of Europe: those of Asia have not yet shaken off this absurd yoke, and it must be acknowledged, that if we except the common maxims of morality, there is no one truth which can boast of having been so generally adopted, and through such a succession

ſucceſſion of ages, as certain ridiculous or pernicious errors.

Euler had ſtudied almoſt every branch of phyſics, anatomy, chemiſtry, botany; but his ſuperiority in mathematics did not permit him to attach the ſlighteſt importance to his proficiency in any other branch of ſcience, though it was ſuch as might have induced a perſon more ſuſceptible of the flattery of ſelf-love to aſpire to the title of an univerſal ſcholar.

The ſtudy of ancient literature, and of the learned languages, had formed part of his education: he retained a taſte for theſe to the end of life, and never forgot any thing he had once acquired; but he had neither time nor inclination to proſecute farther his attainments in claſſic literature. He had not ſo much as read the modern poets, but knew the Eneid by heart. Euler, however, did not loſe ſight of the mathematics, even in reciting the verſes of *Virgil.* Every thing concurred to preſent him with this darling object of his thoughts, and we find among his works, an ingenious memoir on a queſtion in mechanics, the firſt idea of which, he tells us, was ſuggeſted by a line of *Virgil.*

It has been ſaid that, to men of great talents, the pleaſure of exertion is a reward ſtill more gratifying than glory itſelf: were it neceſſary to prove this truth by examples, that of Euler would put it beyond a doubt.

In his moſt profound diſcuſſions with celebrated geometricians, he never betrayed the ſlighteſt ſymptom

tom which could excite a ſuſpicion of his being actuated by motives of ſelf-love. He diſcovered no eagerneſs to aſſert his title to the merit of his diſcoveries; and if any thing in his works was claimed as the diſcovery of another, he was at pains to repair the involuntary offence, even without enquiring too ſcrupulouſly, whether rigid juſtice demanded an abſolute renunciation. Did any one pretend to have detected him in error, if the charge was unfounded, he forgot it; if juſt, he corrected it, without ſtopping to obſerve that, in many caſes, the merit of thoſe who boaſted of having made the detection, conſiſted wholly in an eaſy application of the methods which he himſelf had taught them, to theories, the greateſt difficulties of which he had before-hand removed.

Men of middling ability almoſt always endeavour to make themſelves of conſequence, by an affected ſeverity, proportional to the lofty idea which they wiſh to convey of their underſtanding, or of their genius. Inexorable to all that riſes above them, they give no quarter even to inferiority; ſo that we are tempted to ſay, a ſecret conſciouſneſs ſhews them the neceſſity which they are under of lowering others. An inſtinctive emotion engaged EULER, on the contrary, to celebrate genius the moment that it's firſt exertions had challenged his attention, and without waiting till public opinion courted the ſanction of his ſuffrage.

He has been known to employ his time in reſolving problems

problems already ſolved, which was to procure for him, at moſt, the inferior praiſe of greater elegance, or exactneſs of method; and this with the ſame ardor and perſeverance that he could have exerted in the proſecution of a new truth, the diſcovery of which might have brought him an increaſe of reputation. Beſides, had an ardent deſire of glory actually exiſted in his breaſt, it would have been impoſſible for him, ſuch was the frankneſs of his character, to conceal it's emotions. But the glory which he was ſo little ſolicitous to purſue, ſought and found him out. The ſingular fertility of his genius was a ſtriking phenomenon, even to perſons who were not in a condition to underſtand his works.

Though wholly devoted to geometry, his reputation challenged the attention of men little verſed in that ſcience; and he appeared in the eyes of all Europe not only the firſt of geometricians, but a great man. It is the cuſtom of Ruſſia to beſtow military titles on men wholly unconnected with the ſervice. This is paying homage to a prejudice which would repreſent the profeſſion of a ſoldier as the only title to nobility, but the practice is at the ſame time a direct acknowledgment of it's complete falſity. Some of the *Literati* have even arrived at the rank of Major-General: EULER never had, and indeed never would have, any diſtinction of this ſort; but what title in the power of Princes to beſtow, could do honour to the name EULER? And then, regard for the preſervation of the natural rights of humanity,

humanity, impofes, in fome meafure, the duty of fetting the example of a fage indifference to thefe baubles of human vanity, fo childifh and yet fo dangerous.

Moft of the Princes of the North, to whom he was perfonally known, gave him marks of their efteem, or rather of a veneration which they could not with-hold from the union of a virtue fo fimple with a genius fo vaft and elevated. When the Prince Royal of Pruffia travelled to Peterfburg, he did not wait for a vifit from EULER, but went firft to his houfe, and paffed fome hours by the bed-fide of the venerable old man, holding his hands in his own, with one of EULER's grand-children in his lap, whom early fymptoms of a genius for geometry had rendered the particular object of paternal affection.

All the noted mathematicians of the prefent day are his pupils: there is no one of them who has not formed himfelf by the ftudy of his works, who has not received from him the formules, the method which he employs; who is not directed and fupported by the genius of EULER in his difcoveries. This honour he owes to the revolution effected in the mathematical fciences, by fubjecting all to analyfis; to his indefatigable application, which has enabled him to embrace the whole extent of thefe fciences; to the order in which he has arranged his great works; to the fimplicity, to the elegance, of his formules; to the clearnefs of his methods and demonftrations;

demonstrations; and all this greatly enhanced, by the multiplicity and the choice of his examples. Neither *Newton*, nor *Descartes*, whose influence was once so powerful, has arrived at this pitch of glory; and hitherto, EULER alone, of geometricians, has possessed it entirely, and without a rival.

But, as Professor, he has formed pupils in a peculiar sense his own. Among these, we mention his eldest son, whom the Academy of Sciences elected to supply his place, without any apprehension that this honourable succession granted to the name of EULER, as to that of *Bernouilli*, could ever become a dangerous precedent: a second son, now engaged in the study of medicine, but who, in his youth, obtained from that Academy the prize proposed for determining the alterations of the mean motion of the planets; Mr. *Lexell*, whose premature death has just left a blank in the world of science; and, to mention no more, Mr. *Fuss*, the youngest of his scholars, and the companion of his last labours; who, sent from Bâle to EULER by *Daniel Bernouilli*, has, by his works, done credit to *Bernouilli*'s recommendation, and EULER's instructions, and who, after having paid public homage in the Academy of Petersburg, to his illustrious master, married his granddaughter.

Of sixteen professors belonging to the Academy of Petersburg, eight had been formed by him; and all of them, well known from their productions, and decorated with academic honours, value themselves on being able to add, to all the reſt, that of diſciple to EULER.

He had retained all his facility of thought, and, apparently, all his mental vigour: no decay ſeemed to threaten the ſciences with the ſudden loſs of their great ornament. On the 7th of September, 1783, after amuſing himſelf with calculating on a ſlate the laws of the aſcending motion of air-balloons, the recent diſcovery of which was then making a noiſe all over Europe, he dined with Mr. *Lexell* and his family, talked of *Herſchell*'s planet, and of the calculations which determine it's orbit. A little after he called his grand-child, and fell a playing with him as he drank tea, when ſuddenly, the pipe, which he held in his hand, dropped from it, and he ceaſed to calculate and to breathe.

Such was the end of one of the greateſt and moſt extraordinary men ever produced by the hand of nature: a man whoſe genius was equally capable of the greateſt efforts, and of the moſt unwearied application; who multiplied his productions far beyond what could have been expected from powers merely human, and was, nevertheleſs, original in every one; whoſe head was inceſſantly employed, and his ſpirit always tranquil; who, finally, by a deſtiny unfortunately too rare, united, and that deſervedly, a felicity hardly ever interrupted, to a glory which no one ever diſputed with him.

His death was conſidered as a public loſs, even in the country which he inhabited. The Academy of

Peterſburg went into deep mourning for him, and voted a marble buſt of him, at their own expence, to be placed in their Aſſembly-Hall. An honour ſtill more diſtinguiſhed had already been conferred on him, by that learned body, in his life-time. In an allegorical painting, a figure of Geometry is repreſented leaning on a tablet, exhibiting mathematical calculations, and the characters inſcribed, by order of the Academy, are the formules of his new theory of the moon. Thus, a country which, at the beginning of the preſent century, we conſidered as ſcarcely emerged out of barbariſm, is become the inſtructor of the moſt enlightened nations of Europe, in doing honour to the life of great men, and in embalming their memory: it is ſetting theſe nations an example, which ſome of them may bluſh to reflect, that they have had the virtue neither to propoſe, nor to imitate.

LETTERS

ON

DIFFERENT SUBJECTS

IN

PHYSICS AND PHILOSOPHY.

LETTER I.

Of Magnitude, or Extension.

MADAM,

THE hope of having the honour to communicate, in perſon, to your Highneſs, my leſſons in Geometry, becoming more and more diſtant, which is a very ſenſible mortification to me, I feel myſelf impelled to ſupply perſonal inſtruction by writing, as far as the nature of the objects can permit.

I begin my attempt, by aſſiſting you to form a juſt idea of *magnitude;* producing, as examples, the ſmalleſt as well as the greateſt extenſions of matter actually diſcoverable in the ſyſtem of the Univerſe. And firſt, it is neceſſary to fix on ſome one determinate diviſion of meaſure, obvious to the ſenſes, and of which we have an exact idea, that of a foot, for inſtance. The quantity of this, once eſtabliſhed, and rendered familiar to the eye, will enable us to form the idea of every other quantity, as to length, great or ſmall; the former, by aſcertaining how many feet it contains; and the latter, by aſcertaining what part of a foot meaſures it. For, having the idea of a foot, we have that alſo of it's half, of it's quarter, of it's twelfth part, denominated an inch, of it's hundredth, and of it's thouſandth part; which is ſo ſmall as almoſt to eſcape the ſight. But it is to be remarked, that there are animals, not of greater extenſion than this laſt ſubdiviſion of a foot, which, however, are compoſed of members through which the blood circulates, and which again contain other animals, as diminutive compared to them, as they are compared to us. Hence it may be concluded that animals exiſt, whoſe ſmallneſs eludes the imagination; and that theſe again are diviſible into parts inconceivably ſmaller. Thus, for example, though the ten thouſandth part of a foot be too ſmall for ſight, and, compared to us, ceaſes to be an object of ſenſe, it nevertheleſs ſurpaſſes in magnitude certain complete animals; and muſt, to one of thoſe animals, were it endowed with the power of perception, appear extremely great.

Let us now make the tranſition from theſe minute quantities, in purſuing which the mind is loſt, to thoſe of the greateſt magnitude. You have the idea of a mile;* the diſtance from hence to Magdeburg is computed to be 18 miles;† a mile contains 24,000 feet, and we employ it in meaſuring the diſtance of the different regions of the globe, in order to avoid

* The German mile is equal to 4 3-5ths miles Engliſh, nearly.

† About 83 Engliſh miles.

numbers

numbers, inconceivably great, in our calculations, which muſt be the caſe if we uſed foot inſtead of mile. A mile then, containg 24,000 feet, when it is ſaid that Magdeburg is 18 miles from Berlin, the idea is much clearer, than if the diſtance of theſe two cities were ſaid to be 432,000 feet: A number ſo great almoſt overwhelms the underſtanding. Again, we ſhall have a tolerably juſt idea of the magnitude of the earth, when we are told that it's circumference is about 5,400 miles. And the diameter being a ſtraight line paſſing through the centre, and terminating, in oppoſite directions, in the ſurface of the ſphere, which is the acknowledged figure of the earth, for which reaſon alſo we give it the name of *globe*, the diameter of this *globe* is calculated to be 1720 miles;* and this is the meaſurement which we employ for determining the greateſt diſtances diſcoverable in the heavens. Of all the heavenly bodies the moon is neareſt to us, being diſtant only about 30 diameters of the earth, which amount to 51,600 miles,† or 1,238,400,000 feet; but the firſt computation of 30 diameters of the earth, is the cleareſt idea. The ſun is about 300 times farther from us than the moon; and when we ſay his diſtance is 9,000 diameters of the earth, we have a much clearer idea, than if it were expreſſed in miles, or in feet.

* About 7,920 Engliſh miles. The diameter of our earth is really 7,964 Engliſh miles, it's circumference 25,020. The mean diſtance of the moon is 240,000 miles, which ſcarcely exceeds the 400th part of the ſun's mean diſtance, or 93,720,000 miles.

† About 237,360 miles Engliſh.

You know that the earth performs a revolution round the ſun in the ſpace of a year, but that the ſun remains fixed. Beſide the earth, there are five other ſimilar bodies, named planets, which revolve round the ſun; two of them at ſmaller diſtances, Mercury and Venus; and three at greater, namely Mars, Jupiter and Saturn. All the other ſtars which we ſee, comets excepted, are called fixed; and their diſtance from us is incomparably greater than that of the ſun. The diſtances are undoubtedly very unequal, which is the reaſon that ſome of theſe bodies appear greater than others. But the neareſt of them is, unqueſtionably, above 5,[illegible] times more diſtant than the Sun: it's diſtance from us, accordingly, exceeds 45,000,000 of times the earth's diameter, that is 77,400,000,000 of miles;* and this again multiplied by 24,000 will give that prodigious diſtance expreſſed in feet. And this, after all, is the diſtance only of thoſe fixed ſtars which are the neareſt to us; the moſt remote which we ſee, are perhaps a hundred times farther off. It is probable, at the ſame time, that all theſe ſtars taken together, conſtitute only a very ſmall part of the whole univerſe, relatively to which theſe prodigious diſtances are not greater than a grain of ſand compared to the earth. This immenſity is the work of the Almighty, who governs the greateſt bodies and the ſmalleſt.†

Berlin, 19th April, 1760.

* 356,050,000,000 miles Engliſh.

† This letter, in the original edition, that of Leipſig, 1770, is [illegible] *Berlin* 19th April, 1760, and concludes with theſe words, (which

LETTER II.

Of Velocity.

FLATTERING myſelf that your Highneſs may be pleaſed to accept the continuation of my inſtructions, a ſpecimen of which I took the liberty of preſenting to you in a former letter, I procced to unfold the idea of velocity, which is a particular ſpecies of extenſion, and ſuſceptible of increaſe and of diminution. When a ſubſtance is tranſported, that is, when it paſſes from one place to another, we aſcribe to it a velocity. Let two perſons, the one on horſeback, the other on foot, proceed from Berlin to Magdeburg, we have, in both caſes, the idea of a certain velocity; but it will be immediately affirmed, that the velocity of the former exceeds that of the latter. The queſtion then is, Wherein conſiſts the

(which are with great propriety omitted by the philoſophic French editor of the work, twenty-ſeven years afterwards) *and who is now crowning with ſucceſs the arms in which we are ſo deeply intereſted.* This is, no doubt, a dreadful "falling off" from the majeſty of the ſubject. Who cares *now* about the ſucceſs of the Pruſſian arms in 1760? But philoſophers, as well as other men, are under the dominion of local and temporary circumſtances. Frederick II. was then in the zenith of his glory; Euler was living at Berlin, and giving leſſons in philoſophy to the niece of that illuſtrious prince. Is it to be wondered, then, that he ſhould ſink for a moment into the courtier, and offer a drachm of incenſe to a great lady; or, that a ſoul ſo uniformly devout, ſhould acknowledge the providence of the Almighty in a particular inſtance?

city with which I am able to walk. Now it is eafy to comprehend what is meant by a greater or lefs velocity. For if a courier were to go from hence to Magdeburg in 12 hours, his velocity would be the double of mine: if he went in eight hours, his velocity would be triple. We remark a very great difference in the degrees of velocity. The tortoife furnifhes an example of a velocity extremely fmall. If fhe advances only one foot in a minute, her velocity is 300 times lefs than mine, for I advance 300 feet in the fame time. We are likewife acquainted with velocities much greater. That of the wind admits of great variation. A moderate wind goes at the rate of 10 feet in a fecond, or 600 feet in a minute; its velocity therefore is the double of mine. A wind that runs 20 feet in a fecond, or 1200 in a minute, is rather ftrong; and a wind which flies at the rate of 50 feet in a fecond is extremely violent, though its velocity is only 10 times greater than mine, and would take two hours and twenty-four minutes to blow from hence to Magdeburg.

The velocity of found comes next, which moves 1000 feet* in a fecond, and 60,000 in a minute. This velocity, therefore, is 200 times greater than that of my pace; and were a cannon to be fired at Magdeburg, if the report could be heard at Berlin, it

* The velocity of found is generally computed at 1,142 feet each fecond, but varies with the elafticity and denfity of the air. The earth travels in her orbit 1,612,000 miles in the fpace of 24 hours, and therefore with a velocity more than 50 times greater than that of a cannon ball. Light moves about 13 millions of miles every minute.

would arrive there in ſeven minutes. A cannon ball moves with nearly the ſame velocity; but when the piece is loaded to the utmoſt, the ball is ſuppoſed capable of flying 2,000 feet in a ſecond, or 120,000 in a minute. This velocity appears prodigious, though it is only 400 times greater than that of my pace in walking to Lytzow; it is at the ſame time the greateſt velocity known upon earth. But there are in the heavens velocities far greater, though their motion appears to be extremely deliberate. You know that the earth turns round on it's axis in 24 hours: every point of it's ſurface, then, under the equator, moves 5,400 miles* in 24 hours, while I am able to get through only 18 miles.† It's velocity is accordingly 300 times greater than mine, and leſs notwithſtanding than the greateſt poſſible velocity of a cannon ball. The earth performs it's revolution round the ſun in the ſpace of a year, proceeding at the rate of 128,250 miles‡ in 24 hours. It's velocity, therefore, is 18 times more rapid than that of a cannon ball. The greateſt velocity of which we have any knowledge is, undoubtedly, that of light, which moves 2,000,000 of miles § every minute, and exceeds the velocity of a cannon ball 400,000 times.

22d April, 1760.

* 24,840 Engliſh miles

† About 83 Engliſh.

‡ 589,950 Engliſh.

§ 9,200,000 miles Engliſh.

LETTER

LETTER III.

Of Sound, and it's Velocity.

THE elucidations of the different degrees of velocity, which I have had the honour to lay before your Highneſs, carry me forward to the examination of ſound, or noiſe in general. It muſt be remarked, that a certain portion of time always intervenes before ſound can reach our ears, and that this time is longer in proportion to our diſtance from the place where the ſound is produced; a ſecond of time being requiſite to convey ſound 1000 feet.

When a cannon is fired, thoſe who are at a diſtance do not hear the report for ſome time after they have ſeen the flaſh. Thoſe who are a mile, or 24,000 feet diſtant, hear not the report till 24 ſeconds after they ſaw the flame. You muſt no doubt have frequently remarked, that the noiſe of thunder reaches not the ear for ſome time after the lightning: and it is by this we are enabled to calculate our diſtance from the place where the thunder is generated. If, for example, we obſerve that 20 ſeconds intervene between the flaſh and the thunder-clap, we may conclude that the ſeat of the thunder is 20,000 feet diſtant, allowing 1000 feet of diſtance for every ſecond of time. This primary property leads us to inquire, In what ſound conſiſts? Whether it's nature is ſimilar to that of ſmell, that is, whether ſound iſſues from the body which produces it, as ſmell is emitted

emitted from the flower, by filling the air with fubtile exhalations, proper to affect our fenfe of fmelling. This opinion was formerly entertained, but it is now demonftrated, that from a bell ftruck nothing proceeds that is conveyed to our ear, and that the body which produces found lofes no part of it's fubftance. When we look upon a bell that is ftruck, or the ftring of an inftrument when touched, we perceive that thefe bodies are then in a ftate of trembling, or agitation, by which all their parts are affected; and that all bodies, fufceptible of fuch an agitation of their parts, likewife produce found. Thefe fhakings or vibrations are vifible in the ftring of an inftrument when it is not too fmall; the tenfe ftring A C B paffes alternately into the fituation A M B and A N B. (*See plate I. fig.* 1. *in which I have reprefented thefe vibrations much more obvious to fenfe than they are in fact.*) It muft be further obferved, that thefe vibrations put the adjacent air into a fimilar vibration, which is fucceffively communicated to the more remote parts of the air, till it come at length to ftrike our organ of hearing. It is the air, then, which receives thefe vibrations, and which tranfmits the found to our ear. Hence it is evident, that the perception of found is nothing elfe but the impreffion made on our ear by the concuffion of the air, communicated to us through the organ of hearing; and when we hear the found of a ftring touched, our ear receives from the air as many ftrokes as the ftring performs vibrations in the fame time. Thus, if the ftring performs 100 vibrations in a fecond,

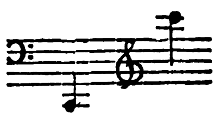
cond, the ear likewiſe receives 100 ſtrokes in the ſame time; and the perception of theſe ſtrokes is what we call ſound. When theſe ſtrokes ſucceed each other uniformly, or when their intervals are all equal, the ſound is regular, and ſuch as is requiſite to muſic. But when the ſtrokes ſucceed unequally, or when their intervals are unequal among themſelves, an irregular noiſe, incompatible with muſic, is the reſult. On conſidering ſomewhat more attentively the muſical ſounds, whoſe vibrations take place equally, I remark firſt, that when the vibrations, as well as the ſtrokes impreſſed on the ear, are more or leſs ſtrong, no other difference of ſound reſults from it, but that of ſtronger or weaker, which produces the diſtinction, termed by muſicians, *fortè & piano.* But there is a difference much more eſſential, when the vibrations are more or leſs rapid, that is, when more or fewer of them are performed in a ſecond. When one ſtring makes 100 vibrations in a ſecond, and another ſtring makes 200 vibrations in the ſame time, their ſounds are eſſentially different; the former is lower or more flat, and the other higher or more ſharp. Such is the real difference between the flat and ſharp ſounds, on which all muſic hinges, and which teaches how to combine ſounds different in reſpect of flatneſs and ſharpneſs, but in ſuch a manner as to produce an agreeable harmony. In the flat ſounds there are fewer vibrations in the ſame time than in the ſharp ſounds; and every key of the harpſichord contains a certain and determinate number of vibrations, which are completed in a ſecond.

Thus

Thus the note marked by the letter C,* makes nearly 100 vibrations in a ſecond; and the note marked $\overset{\equiv}{c}$ makes 1600 vibrations in the ſame ſpace of time. A ſtring which vibrates 100 times in a ſecond, will give preciſely the note C; and if it vibrated only 50 times, the note would be lower or more flat. But with regard to our ear, there are certain limits beyond which ſound is no longer perceptible. It would appear that we are incapable of determining either the ſound of a ſtring which makes leſs than 30 vibrations in a ſecond, becauſe it is too low; or that of a ſtring which would make more than 7552 in a ſecond, becauſe ſuch a note would be too high.

26th April, 1760.

* The note C is that which is produced by touching the thickeſt ſtring of a violoncello; the note $\overset{\equiv}{c}$ is the fourth octave of the firſt; accordingly, theſe two notes, repreſented by the uſual method of pricking muſic, are



Mr. Euler marks the progreſſion of octaves thus:

	1ſt octave,	2d octave,	3d octave,	4th octave.
C, or *ut*.	c.	$\overline{c}$	$\overset{=}{c}$	$\overset{\equiv}{c}$

and in like manner for the other notes of the gamut; D. E. F. G. A. B. or *re*, *mi*, *fa*, *ſol*, *la*, *ſi*.

In writing the chromatic ſcale, he employs the following ſigns:

C.	Cs,	D,	Ds,	E,	F,	Fs,	G,	Gs,	A,	B,	H,	c
ut,	*ut*♯,	*re*,	*re*♯,	*mi*,	*fa*,	*fa*♯,	*ſol*,	*ſol*♯,	*la*,	*ſi*♭,	*ſi*♮,	*ut*.

LETTER

LETTER IV.

Of Consonance and Dissonance.

I RESUME my remark, that on hearing a ſimple muſical ſound, our ear is ſtruck with a ſeries of ſtrokes equally diſtant from each other, the frequency and number of which, in a given ſpace of time, conſtitute the difference which ſubſiſts between low notes and high: ſo that, the ſmaller the number of vibrations or ſtrokes produced in a given time, ſay a ſecond, the lower we eſtimate that note; and the greater the number of ſuch vibrations, the higher is the note. The perception of a ſimple muſical ſound may, therefore, be compared to a ſeries of dots equidiſtant from each other, as . . . . If the intervals between theſe dots be greater or ſmaller, the ſound produced will be lower or higher. It cannot be doubted, that the perception of a ſimple ſound is ſomewhat ſimilar or analogous to the ſight of ſuch a ſeries of dots equidiſtant from each other: we are enabled thus to repreſent to the eye what the ear perceives on hearing ſound. If the diſtances between the dots were not equal, or were theſe dots ſcattered about confuſedly, they would be a repreſentation of a confuſed noiſe, inconſiſtent with harmony. This being laid down, let us conſider what effect two ſounds emitted at once muſt produce on the ear. Firſt, it is evident, that if two ſounds are equal, or if each performs the ſame number of vibrations in the

the ſame time, the ear will be affected in the very ſame manner as by a ſingle note; and, in muſic, theſe two notes are ſaid to be in uniſon, which is the ſimpleſt *accord:* we mean by the term *accord* the blending of two or more ſounds heard at once. But if two ſounds differ in reſpect of low and high, we ſhall perceive a mixture of two ſeries of ſtrokes, in each of which the intervals are equal among themſelves, but greater in the one than in the other; the greater intervals correſponding to the lower note, and the ſmaller to the higher. This mixture, or this accord of two notes, may be repreſented to the eyes by two ſeries of dots arranged on two lines A B and C D;

```
    1  2  3  4  5  6  7  8  9  10 11
A . . . . . . . . . . . . . . B
C . . . . . . . . . . . . . . D
    1  2  3  4  5  6  7  8  9  10 11 12
```

and in order to form a juſt idea of theſe two ſeries, we muſt have a clear perception of the order which ſubſiſts among them, or, in other words, of the relation between the intervals of the one line and of the other. Having numbered and marked the dots of each line, and placed No. 1. under No. 1; thoſe marked with the figure 2, will not exactly correſpond, and ſtill leſs thoſe marked 3: but we find No. 11 exactly over No 12: from which we diſcover that the higher note makes 12 vibrations, and the other only 11. If we had not affixed the figures, the eye would hardly have perceived this order; it is the ſame with the ear, which would with much difficulty

difficulty have traced it in the two notes which I have repreſented by two rows of dots. But in the following figure,

. . . .

. . . . . .

you diſcover at the firſt glance that the upper line contains twice as many dots as the under, or that the intervals in the under line are twice as great as thoſe of the upper. This is undoubtedly, next to uniſon, the ſimpleſt of all caſes, in which you can at once diſcover the order which ſubſiſts between theſe two ſeries of dots; and the ſame thing holds with reſpect to the two notes repreſented by theſe two lines of dots: the number of vibrations contained in the one will be preciſely the double of the vibrations contained in the other, and the ear will eaſily perceive the pleaſing relation of theſe two ſounds; whereas, in the preceding caſe, it was extremely difficult, if not impoſſible, to diſcriminate. When the ear readily diſcovers the relation ſubſiſting between two notes, their accord is denominated *conſonance:* and if it be very difficult, or even impoſſible to catch this relation, the accord is termed *diſſonance.* The ſimpleſt conſonance, then, is that in which the high note produces preciſely twice as many vibrations as the low note. This conſonance, in the language of muſic, is called *octave:* every one knows what it means; and two notes which differ preciſely an octave, harmonize ſo perfectly, and poſſeſs ſuch a complete reſemblance, that muſicians mark them by the ſame letters. Hence it is that in church-muſic the

the women ſing an octave higher than the men, and yet imagine they are uttering the ſame ſounds. You may eaſily aſcertain the truth of this by touching the keys of a harpſichord, when you will perceive with pleaſure the delightful accord of all the notes which are juſt an octave diſtant, whereas any other two notes whatever will ſtrike the ear leſs agreeably.

29th April, 1760.

LETTER V.

Of Uniſon and Octaves.

YOUR Highneſs has by this time remarked, that the accord which muſicians call an octave, ſtrikes the ear in a manner ſo decided, that the ſlighteſt deviation is eaſily perceptible. Thus, having touched the Key marked F, that marked f, which is an octave higher, is eaſily attuned to it, by the judgment of the ear only. If the ſtring which is to produce this note be ever ſo little too high or too low, the ear is inſtantly offended, and nothing is eaſier than to put the two keys perfectly in tune. Thus we obſerve, that in ſinging the voice ſlides eaſily from one note to another, which is juſt an octave higher or lower. But were it required to paſs immediately from the note F to the note d, for example, an ordinary ſinger might eaſily fall into a miſtake, unleſs aſſiſted by an inſtrument. Having fixed the note F, it is almoſt impoſſible all at once to make the tranſition to the note d. What then is the reaſon of this

this difference, that it is ſo eaſy to make note f harmonize with note F, and ſo difficult to make note d accord with it? The reaſon is evident from the remarks already made: it is this, that note F and note f make an octave, and that the number of vibrations of note f is preciſely double that of note F. In order to have the perception of this accord, you have only to conſider the proportion of one to two, which, as it inſtantly ſtrikes the eye by the repreſentation of the dots I formerly employed, affects the ear in a ſimilar manner. You will eaſily comprehend, then, that the more ſimple any proportion is, or expreſſed by ſmall numbers, the more diſtinctly it preſents itſelf to the underſtanding, and conveys to it a ſentiment of ſatisfaction.* Architects likewiſe carefully attend to this maxim, as they uniformly employ in their works proportions as ſimple as circumſtances permit. They uſually make the height of doors and windows double the breadth, and endeavour to employ throughout proportions capable of being expreſſed by ſmall numbers, becauſe this is obvious and grateful to the underſtanding. The ſame thing holds good in muſic: accords are pleaſing only in ſo far as the mind perceives the relation ſubſiſting between the ſounds, and this relation is ſo much more

* In order to have a clear conception of what follows, it muſt be recollected, that the terms *relation* and *ratio* are ſynonimous, and that the author is here conſidering geometrical proportion, which conſiſts in the number of times that the firſt term is contained in the ſecond.—*F. E.*

eaſily perceptible, as it is expreſſed by ſmall numbers. Now, next to the relation of equality, which denotes two ſounds in uniſon, the ratio of two to one is undoubtedly the moſt ſimple, and it is this which furniſhes the accord of an octave: hence it is evident, that this accord poſſeſſes many advantages above every other conſonance. Having thus explained the accord, or interval of two notes denominated by muſicians an octave, let us conſider ſeveral notes, as F, f, $\bar{f}$, $\bar{\bar{f}}$, $\bar{\bar{\bar{f}}}$ each of which is an octave higher than the one immediately preceding: ſince then the interval of F from f, of f from $\bar{f}$, of $\bar{f}$ from $\bar{\bar{f}}$, of $\bar{\bar{f}}$ from $\bar{\bar{\bar{f}}}$ is an octave, the interval of F to $\bar{f}$ will be a double octave, that of F to $\bar{\bar{f}}$ a triple octave, and that of F to $\bar{\bar{\bar{f}}}$ a quadruple octave. Now, while note F makes one vibration, note f makes two, note $\bar{f}$ makes four, note $\bar{\bar{f}}$ makes eight, and note $\bar{\bar{\bar{f}}}$ makes ſixteen: hence we ſee, that as an octave correſponds in the relation of 1 to 2, a double octave muſt be in the ratio of 1 to 4, a triple in that of 1 to 8, and a quadruple in that of 1 to 16. And the ratio of 1 to 4, not being ſo ſimple as that of 1 to 2, for it does not ſo readily ſtrike the eye, a double octave is not ſo eaſily perceptible to the ear as a ſingle; a triple is ſtill leſs perceptible, and a quadruple ſtill much leſs ſo. When, therefore, in tuning a harpſichord, you have fixed the note F, it is not ſo eaſy to attune the double octave $\bar{f}$ as the ſingle f; it is ſtill more difficult attune the triple octave $\bar{\bar{f}}$ and the quadruple $\bar{\bar{\bar{f}}}$ hout riſing through the intermediate octaves.

Theſe

Thefe accords are likewife comprehended in the term confonance; and as that of unifon is moft fimple, they may be arranged according to the following gradations:

I. Degree, unifon, indicated by the relation of 1 to 1.
II. Degree, the immediate octave, in the ratio of 1 to 2.
III. Degree, the double octave, in that of 1 to 4.
IV. Degree, the triple octave, in that of 1 to 8.
V. Degree, the quadruple octave, in that of 1 to 16.
VI. Degree, the quintuple octave, in that of 1 to 32.

And fo on, as long as found is perceptible. Such are the accords denominated confonances, to the knowledge of which we have been thus far conducted; but hitherto we know nothing of the other fpecies of confonance, and ftill lefs of the diffonances employed in mufic. Before I proceed to the explication of thefe, I muft add one remark refpecting the name octave, given to the interval of two notes, the one of which contains twice the vibrations contained in the other. You fee the reafon of it in the principal ftops of the harpfichord, which rife by feven degrees before you arrive at the octave C, D, E, F, G, A, B, c, fo that ftop c is the eighth, reckoning C the firft. And this divifion depends on a certain feries of mufical intervals, the nature of which fhall be unfolded in the following letters.

3d May, 1760.

LETTER VI.

Of other Consonances.

IT may be affirmed, that the relations of one to 2, of 1 to 4, of 1 to 8, of 1 to 16, which we have hitherto considered, and which contain the progression of octaves, are all formed by the number 2 only; since 4 is 2 times 2; 8, 2 times four; 16, two times 8. Were we to admit, therefore, the number 2 alone into music, we should arrive at the knowledge of only the accords or consonances which musicians call the single, double, or triple octave; and as the number 2, by its reduplication, furnishes only the numbers 4, 8, 16, 32, 64, the one being always double the preceding, all other numbers would remain unknown. Now, did an instrument contain octaves only, as the notes marked C, c, $\bar{c}$, c, $\bar{\bar{c}}$, and were all others excluded, it could not produce an agreeable music, on account of its too great simplicity. Let us introduce, then, together with number 2, the number 3 likewise, and observe what accords or consonances would be the result. The ratio of 1 to 3 presents at once two sounds, the one of which makes 3 times more vibrations than the other in the same time. This ratio is undoubtedly the most easily to be comprehended, next to that of 1 to 2; it will, accordingly, furnish very pleasing consonances, but of a nature totally different from that of octaves. Let us suppose, then, that in the proportion of 1

to

to 3, number 1 correſponds to note C; ſince note c is expreſſed by number 2, number 3 gives a ſound higher than c, but at the ſame time lower than note $\bar{c}$, which correſponds to number 4. Now, the note expreſſed by 3 is that to which muſicians affix the letter g, and they denominate the interval from c to g, *a fifth*, becauſe in the keys of a harpſichord that of g is the fifth from c, as c, d, e, f, g. If then number 1 produces the ſound C, number 2 will give c; number 3 gives g, number 4 the note $\bar{c}$; and note $\bar{g}$ being the octave of g, the number correſponding to it will be 2 times 3, or 6. Riſing ſtill an octave, the ſound $\bar{\bar{g}}$ will correſpond to a number twice greater, that is 12. All the notes with which the two numbers 2 and 3 furniſh us, indicating note C by 1, therefore are,

$$\begin{array}{cccccccc} C, & c, & g, & \bar{c}, & \bar{g}, & \bar{\bar{c}}, & \bar{\bar{g}}, & \bar{\bar{\bar{c}}} \\ 1. & 2. & 3. & 4. & 6. & 8. & 12. & 16. \end{array}$$

Hence it is clear, that the ratio of 1 to 3 expreſſes an interval, compounded of an octave and a fifth, and that this interval, on account of the ſimplicity of the numbers which repreſent it, muſt be, next to the octave, the moſt grateful to the ear. Muſicians accordingly aſſign the ſecond rank among conſonances to the fifth; and the ear catches it ſo eaſily, that there is no difficulty in tuning a fifth. For this reaſon, in violins, the four ſtrings riſe by fifths, the loweſt being g, the ſecond $\bar{d}$, the third $\bar{a}$, and the fourth $\bar{\bar{e}}$;* and every muſician puts them in tune

* That is, in the language of *ſol-faing*, *ſol*, *re*, *la*, *mi*.

by the ear only. A fifth, however, is not ſo eaſily tuned as an octave; but the fifth above the octave, as from C to g, being expreſſed by the proportion of 1 to 3, is more perceptible than a ſimple fifth, as from C to G, or from c to g, which is expreſſed by the proportion of 2 to 3: and it is likewiſe known by experience, that having fixed the note C, it is eaſier to attune to it the higher fifth g, than the ſimple G. If unity had marked the note F, number 3 would mark the note $\bar{c}$, ſo that,

F, f, $\bar{c}$, $\bar{f}$, $\bar{\bar{c}}$, $\bar{\bar{f}}$, $\bar{\bar{\bar{c}}}$, would be marked by

1. 2. 3. 4. 6. 8. 12. where, from f to c the interval is a fifth in the relation of 2 to 3; from $\bar{f}$ to $\bar{\bar{c}}$, from $\bar{\bar{f}}$ to $\bar{\bar{\bar{c}}}$ are alſo fifths, as the ratio of 4 to 6, and of 8 to 12, is the ſame as that of 2 to 3. For if two ſtrings perform, in the ſame time, the one 4 vibrations, the other 6, the former ſtring will make, in a time equal to half the firſt ſpace of time, two vibrations, and the ſecond, in the ſame time, will make three. Now the ſounds emitted from theſe ſtrings are the ſame in both caſes; of conſequence the relation of 4 to 6 expreſſes the ſame interval as that of 2 to 3, that is, a fifth. Hence we have arrived at the knowledge of another interval contained in the ratio of 3 to 4, which is that of $\bar{c}$ to $\bar{f}$, and conſequently alſo of c to f, or of C to F. Muſicians call it *a fourth;* and being expreſſed by greater numbers, it is not ſo agreeable, by a great deal, as the fifth, and ſtill leſs ſo than the octave. Number 3 having furniſhed us new accords or conſonances, namely the fifth and the

fourth,

fourth, before we call in any others, let us take it again three times, in order to have the number 9, which will give a higher note than note 3*, or $\bar{c}$ one octave and one fifth. Now, $\bar{\bar{c}}$ is the octave of $\bar{c}$, and $\bar{\bar{g}}$ the fifth of $\bar{\bar{c}}$; number 9 then gives the note $\bar{\bar{g}}$, so that $\bar{\bar{c}}$, $\bar{\bar{f}}$, $\bar{\bar{g}}$, $\bar{\bar{\bar{c}}}$, will be marked by

6. 8. 9. 12; and if these notes be taken in the lower octaves, the relations remaining the same, we shall have;

C, F, G; c, f, g; $\bar{c}$, $\bar{f}$, g; $\bar{c}$, $\bar{\bar{f}}$, $\bar{\bar{g}}$; $\bar{\bar{\bar{c}}}$.
6. 8. 9; 12. 16. 18; 24. 32. 36; 48. 64. 72. 96.
which leads us to the knowledge of new intervals.

The first is that of F to G, contained in the ratio of 8 to 9, which musicians call a *second* or *tone*. The second is that of G to f, contained in the ratio of 9 to 16; called a *seventh*, and which is one second, or one tone less than an octave. These proportions, being already expressed by very great numbers, are not reckoned among the consonances, and musicians call them *dissonances* or *discords*.

Again, if we take three times the number 9, or 27, it will mark a tone higher than $\bar{c}$, and precisely a fifth higher than g; it will be accordingly the tone $\bar{d}$, and it's octave $\bar{\bar{d}}$ will correspond to twice the number 27, or 54, and it's double octave $\bar{\bar{\bar{d}}}$ to twice the

* Great care must be taken to guard ourselves from affixing to numbers the idea of a perfect identity with the sounds which they represent. The first express only the relation of the number of vibrations performed in the same time, by the bodies which emit the sounds in question. There is no real analogy between number and sound.—*F. E.*

number, 54, or 108. Let us repreſent theſe tones ſome octaves lower, in the manner following:

C,	D,	F,	G;	c,	d,	f,	g,	$\bar{c}$,	$\bar{d}$,	$\bar{f}$,
24,	27,	32,	36;	48,	54,	64,	72;	96,	108,	128,
$\bar{g}$;	$\bar{\bar{c}}$,	$\bar{\bar{d}}$,	$\bar{\bar{f}}$,	$\bar{\bar{g}}$;	$\bar{\bar{\bar{c}}}$.					
144;	192,	216,	256,	288;	384.					

Hence we ſee, that the interval from D to F is contained in the ratio of 27 to 32, and that of F to d in the ratio of 32 to 54, the two terms of which are diviſible by 2; and then in place of this relation we have that of 16 to 27. The firſt interval is called a *tierce minor*, or *leſſer third*, and the other a *greater ſixth*. The number 27 might be ſtill farther multiplied by 3, but muſic extends not ſo far, and we limit ourſelves to number 27, reſulting from 3, multiplied three times by itſelf: other muſical tones ſtill wanting are introduced by means of number 5, and ſhall be unfolded in my next Letter.

3d *May*, 1760.

LETTER VII.

Of the twelve Tones of the Harpſichord.

THE preſent ſubject of my correſpondence with your Highneſs is ſo dry, that I begin to apprehend it may be growing tireſome. That I may not waſte too much time on it, and be relieved from the neceſſity of recurring frequently to a topic ſo diſ-

guſting,

guſting, I ſend you by this conveyance three letters at once. My intention, in undertaking it, was to render viſible the real origin of muſical notes, with which muſicians themſelves are almoſt totally unacquainted. It is not to theory they are indebted for the knowledge of all theſe ſounds; but rather to the ſecret power of genuine harmony, operating ſo efficaciouſly on their ears, that they have been conſtrained, if I may be allowed to ſay it, to receive tones actually in uſe, though they are not hitherto perfectly agreed reſpecting their juſt determination. The principles of harmony are ultimately reducible to numbers,* as I have demonſtrated; and it has been remarked, that the number 2 furniſhes octaves only, ſo that having fixed, for example, the note F, we are conducted to the notes f, $\bar{f}$, $\bar{\bar{f}}$, $\bar{\bar{\bar{f}}}$. The number 3 afterwards furniſhes C, c, $\bar{c}$, $\bar{\bar{c}}$, $\bar{\bar{\bar{c}}}$, which differ one fifth from the preceding ſeries; and the repetition of this ſame number 3, furniſhes again the fifths of the firſt, namely G, g, $\bar{g}$, $\bar{\bar{g}}$, $\bar{\bar{\bar{g}}}$: and finally, the third repetition of this number 3 adds farther the notes D, d, $\bar{d}$, $\bar{\bar{d}}$, $\bar{\bar{\bar{d}}}$. The principles of harmony then being attached to ſimplicity, ſeem to forbid our puſhing farther the

* This is true only to a certain degree; for, if we except the knowledge of the relation of notes, or the numerical expreſſion of intervals, numbers cannot be introduced into muſic, as Mr. d'Alembert has juſtly remarked, but as a piece of uſeleſs parade; and the ſcanty knowledge they furniſh is far ſhort of the theory of compoſition, which is founded on the pleaſure of the ear, and hitherto no one has attempted to make this a ſubject of calculation. —*F. E.*

repetition

theſe ſounds only, we are in a condition to compoſe harmonies very agreeable and various, the beauty of which is founded on the ſimplicity alone of the numbers correſponding to the notes. Finally, upon applying, a ſecond time, the number 5, we ſhall be furniſhed with the thirds of the four new tones, A, E, B, Fs, which we have juſt found, we ſhall have the notes Cs Gs Ds and B, ſo that now the octave is completed of the 12 tones received in muſic. All theſe tones derive their origin from the three numbers 2, 3, and 5, multiplying 2 by itſelf, as often as the octaves require; but we carry the multiplication of 3 only to the third ſtage, and of five to the ſecond. All the tones of the firſt octave are contained in the following table, in which you will ſee how the fundamental numbers 2, 3, and 5, enter into the compoſition of thoſe which expreſs the relation of theſe notes.

			Difference.
ut or C	2, 2, 2, 2, 2, 2, 2, 3 . . .	384	
ut ♯ Cs	2, 2, 2, 2, 5, 5	400	16
re D	2, 2, 2, 2, 3, 3, 3.	432	32
re ♯ Ds	2, 3, 3, 5, 5.	456	18
mi E	2, 2, 2, 2, 2, 3, 5.	480	30
fa F	2, 2, 2, 2, 2, 2, 2, 2, 2. .	512	32
fa ♯ Fs	2, 2, 3, 3, 3, 5	540	28
ſol G	2, 2, 2, 2, 2, 2, 3, 3 . . .	576	36
ſol ♯ Gs	2, 2, 2, 3, 5, 5	600	24
la A	2, 2, 2, 2, 2, 2, 2, 5 . . .	640	40
ſi b. B♭	3, 3, 3, 5, 5.	675	35
ſi ♮ B♮	2, 2, 2, 2, 3, 3, 5.	720	45
ut c	2, 2, 2, 2, 2, 2, 2, 3, 3. .	768	48

While

While note C makes 384 vibrations, the tone Cs gives 400, and the others as many as are marked by their correſponding numbers: note c will give then, in the ſame time, double the number of vibrations marked by 384, that is 768. And for the following octaves, you have only to multiply theſe numbers by 2, by 4, or by 8. Accordingly note $\bar{c}$ will give twice 768, or 1536 vibrations, note $\bar{\bar{c}}$ twice 1536, or 3072 vibrations, and note $\bar{\bar{\bar{c}}}$ twice 3072, or 6144 vibrations. In order to comprehend the formation of ſounds, by means of theſe numbers 2, 3, and 5, it muſt be remarked, that the points placed between the numbers in the preceding table ſignify that they are multiplied into each other; thus, taking the tone Fs, for example, the expreſſion 2, 2, 3, 3, 3, 5, ſignifies 2 multiplied by 2, that product by 3, that again by 3, that again by 3, and that by 5. Now 2 by 2 make 4, that by 3 make 12, that by 3 make 36, that by 3 make 108, and that by 5 make 540. Hence it is ſeen that the differences between theſe tones are not equal among themſelves; but that ſome are greater, and others leſs. This is what real harmony requires. The inequality, however, not being conſiderable, we commonly look on all theſe differences as equal, denominating the interval from one note to another, *ſemitone;* and thus the octave is divided into 12 *ſemitones*. Many modern muſicians make them equal, though this be contrary to the principles of harmony, becauſe no one fifth or third is perfectly exact, and the effect is the ſame as if theſe tones were

not

not perfectly in tune.* They likewise admit, that we must give up exactness of accord in order to obtain the advantage of equality of semitones, so that the transposition from any one tone whatever to another may in no respect injure the melody. They acknowledge, however, that the same piece played in the tone C, or a half tone higher, that is Cs, must considerably affect it's nature. It is evident, therefore, that in fact all semitones are not equal, whatever efforts may be made by musicians to render them such; because true harmony resists the execution of a design contradictory to it's nature. Such, then, is the real origin of the musical notes already in use; they are derived from the numbers 2, 3, and 5. Were we farther to introduce number 7, that of the tones of an octave would be increased, and the art of music carried to a higher degree of perfection. But here the mathematician gives up the musician to the direction of his ear.

3*d May*, 1760.

* The alteration thus forced upon the fifths, in order that every key of the harpsichord may serve equally for the higher note flattened, and for the lower sharpened, and that, at the end of the subdivision, the octaves may be exact, is called *temperament*. It has been remarked that fifths may be a little weakened without hurting the ear very much; whereas greater thirds become harsh and disagreeable when they are strengthened.—*F. E.*

LETTER

LETTER VIII.

Of the Pleasure derived from fine Music.

IT is a queſtion as important as curious, Whence is it that a fine piece of muſic excites a ſentiment of pleaſure? The learned differ on this ſubject. Some pretend that it is mere caprice, and that the pleaſure produced by muſic is not founded on reaſon, becauſe what is grateful to one is diſguſting to another. This, far from deciding the queſtion, renders it only more complicated. The very point to be determined is, How comes it, that the ſame piece of muſic produces effects ſo different, ſeeing all admit that nothing happens without reaſon? Others maintain that the pleaſure derived from fine muſic conſiſts in the perception of the order which pervades it. This opinion appears at firſt ſight ſufficiently well founded, and merits a more attentive examination. Muſic preſents objects of two kinds, in which order is eſſential. The one relates to the difference of the ſharp or flat tones; and you will recollect, that it conſiſts in the number of vibrations performed by each note in the ſame time. This difference, which is perceptible between the quickneſs of the vibrations of all ſounds, is what is properly called harmony. The effect of a piece of muſic, of which we feel the relations of the vibrations of all the notes that compoſe it, is the production of harmony. Thus two notes which differ an octave, excite a perception of the relation

lation of 1 to 2; a fifth, of that of 2 to 3; and a greater third, of that of 4 to 5. We comprehend then the order which is found in harmony, when we know all the relations which pervade the notes of which it is compofed, and it is the perception of the ear which leads to this knowledge. This perception more or lefs delicate, determines why the fame harmony is felt by one, and not at all by another, efpecially when the relations of the notes are expreffed by fomewhat greater numbers. Mufic contains, befide harmony, another object equally fufceptible of order, namely the *meafure*, by which we affign to every note a certain duration: and the perception of the meafure confifts in the knowledge of this duration, and of the relations which refult from it. The drum and tymbal furnifh the example of a mufic in which meafure alone takes place, as all the notes are equal among themfelves, and then there is no harmony. There is likewife a mufic confifting wholly in harmony, to the exclufion of meafure. This mufic is the *choral*, in which all the notes are of the fame duration; but perfect mufic unites harmony and meafure. Thus the connoiffeur who hears a piece of mufic, and who comprehends, by the acute perception of his ear, all the proportions on which both the harmony and the meafure are founded, has certainly the moft perfect knowledge poffible of that mufic; while another, who perceives thefe proportions only in part, or not at all, underftands nothing of the matter, or poffeffes at moft a very flender knowledge of it. But the fentiment of pleafure excited

cited by fine mufic muft not be confounded with the knowledge of which I have been fpeaking, though it may be confidently affirmed, that a piece of mufic cannot produce any, unlefs the relations of it are perceived. For this knowledge alone is not fufficient to excite the fentiment of pleafure; fomething more is wanting, which no one hitherto has unfolded. In order to be convinced that the perception alone of all the proportions of a piece of mufic is infufficient to produce pleafure, you have only to confider mufic of a very fimple conftruction, fuch as goes in octaves alone, in which the perception of proportions is undoubtedly the eafieft. Such mufic would be far from conveying pleafure, though you might have the moft perfect knowledge of it. It will be faid then that pleafure requires a knowledge not quite fo eafily attained, a knowledge that occafions fome trouble; which muft, if I may ufe the expreffion, coft us fomething. But, in my opinion, neither is this a fatisfactory folution. A diffonance, the relations of which are expreffed by the higheft numbers, is caught with more difficulty; a feries of diffonances, however, following without choice, and without defign, cannot pleafe. The compofer muft therefore have purfued in his work, a certain plan, executed in real and perceptible proportions. Then a connoiffeur on hearing fuch a piece, and comprehending, befide the proportions, the very plan and defign which the compofer had in view, will feel that fatisfaction which conftitutes the pleafure procured by exquifite mufic to an ear accuftomed to relifh the beauties and deli-

cacies

tacies of that enchanting art. It arifes, then, from divining in fome meafure the views and feelings of the compofer, whofe execution, when fortunate, fills the foul with an agreeable fenfation. It is a fatisfaction fomewhat fimilar to that which is derived from the fight of a well acted pantomime, in which you may conjecture, by the gefture and action, the fentiments and dialogue intended to be expreffed, and which prefents befides a well digefted plan. The enigma of the chimney-fweeper,* which was fo diverting to your Highnefs, furnifhes me with another excellent comparifon. When you can guefs the fenfe, and difcover that it is perfectly expreffed in the propofition of the enigma, you feel a very fenfible pleafure on making the difcovery; but infipid and incongruous enigmas produce none. Such are, if I may be permitted to judge, the true principles on which decifions refpecting the excellency of mufical compofitions are founded.

6th May, 1760.

LETTER IX.

Compreffion of the Air.

THE explanation of found, which I have had the honour to prefent to your Highnefs, leads me forward to a more particular confideration of air, which, being fufceptible of a movement of vibration,

* A celebrated enigma of La Mothe, publifhed in his fugitive pieces.

 fuch

fuch as that by which mufical ftrings, bells, and other fonorous bodies are agitated, tranfmits the concuffion to our ears. It will be immediately afked, What is air? For it does not appear, at firft fight, to be a material fubftance. As we perceive no fenfible body in it, furrounding fpace feems to contain no matter whatever. We feel nothing; we can walk, and move every limb in it, without meeting the flighteft obftacle. But you have only to move your hand brifkly, to be fenfible of fome refiftance, and even to perceive a ftream of wind excited by that rapid movement. Now the wind is nothing elfe but air put in motion; and feeing it is capable of producing effects fo furprifing, how is it poffible to doubt that air is a material fubftance, and confequently a body?* For the terms *body* and *matter* are fynonymous.

Body is divided into two great claffes, folid and fluid. The air, it is evident, muft be referred to the clafs of fluids. It has feveral properties in common with water; but it is much more fubtile and fine. Experiments have afcertained that air is about 800 times more fubtile and more rarefied than water;

* It is an erroneous principle that the air is diftinguifhed from other fluids by it's fufceptibility of compreffion. All fluids are perfectly elaftic, only the force required to produce a certain degree of compreffion differs very widely in each. Thus the fame [illegible]e which caufes water to fuffer a contraction of only the thirty [illegible]ufandth part of it's bulk, condenfes air into one half. The [illegible] diftinction between the aeriform and liquid fluids feems to be, [illegible] the reaction of the former is proportional to their denfity, while that of the latter is proportional to the quantity of compreffion.—*E. E.*

[illegible] and

and that if air were to be rendered 800 times denſer than it is, it would have the ſame conſiſtency as the other fluid. A principal property of air, by which it is diſtinguiſhed from other fluids, is it's quality of being compreſſed, or reduced into a ſmaller ſpace. This is demonſtrated by the following experiment. Take a tube of metal or glaſs A B C D *(plate* I. *fig.* 2.) cloſe ſhut at the end A B, and open at the other, into which is introduced a piſton, filling exactly the cavity of the tube. On puſhing the piſton inwards, when it has arrived at the middle E, the air which occupied at firſt the cavity A B C D will be reduced one half, and conſequently will have become twice as denſe. If the piſton is puſhed ſtill farther in, as far as F, half way between B and E, the air will be reduced to a ſpace four times ſmaller than at firſt; and if you continue to drive forward the piſton to G, ſo that B G ſhall be the half of B F, or the eighth part of the whole length B D, the ſame air which in the beginning was expanded over the whole cavity of the tube, will be contracted to a ſpace eight times ſmaller. Going on in the ſame manner to contract it into a ſpace 800 times ſmaller, you will obtain an air 800 times denſer than ordinary air. It would then be as denſe as water, which it would be eaſy to prove by other experiments. Hence it appears, that air is a fluid ſubſtance, capable of compreſſion, or, in other words, of being reduced to a ſmaller ſpace, and in this reſpect it differs entirely from water. For, let the tube A B C D be filled with this laſt fluid, and attempt to introduce the piſton, you will find it im-

 poſſible

poſſible to drive it forward. Employ what force you may, you will gain nothing; the tube will burſt ſooner than you can reduce the water to a ſpace ſenſibly ſmaller. This then is the eſſential difference between air and water: the latter is ſuſceptible of no compreſſion, but air may be compreſſed to any degree you pleaſe. The more the air is compreſſed, the denſer it becomes; thus the air which occupied a certain ſpace, when compreſſed or reduced to half that ſpace, becomes twice as denſe; if reduced to a ſpace 10 times ſmaller, it is rendered 10 times more denſe; and ſo on. I have already remarked, that could it be rendered 800 times more denſe, it would then be as denſe as water, and conſequently as heavy, for weight increaſes in the ſame proportion as denſity. Gold, the heavieſt ſubſtance with which we are acquainted, is likewiſe the moſt denſe. It is found by experiment to be 19 times heavier than water; and that a maſs of gold, in form of a cube of one foot, would weigh 19 times a maſs of water of the ſame dimenſions. Now ſuch a maſs of water weighs 70 pounds; the maſs of gold therefore would weigh 19 times 70, that is 1330 pounds. It follows that were it poſſible to compreſs air till it were reduced to a ſpace 19 times 800, that is, 15,200 times ſmaller, it would become as denſe and as weighty as gold.

But it is very far from being poſſible to carry the compreſſion of air to that degree. You may at firſt without difficulty drive forward the piſton, but the farther you advance, the reſiſtance becomes more powerful;

powerful; and, before you are able to reduce the air to a ſpace 10 times ſmaller, ſuch a force muſt be employed as would burſt the tube, unleſs it were of uncommon ſtrength. And not only would ſuch a force be neceſſary to drive the piſton farther, but an equal force would be requiſite to keep it in that ſtate, for on the ſlighteſt relaxation of the power, the compreſſed air would drive it backward. The more compreſſed the air is, the more violent are it's efforts to expand, and to recover it's natural ſtate. This is what we call the ſpring or elaſticity of the air, of which I propoſe to treat in my next letter.

10th May, 1760.

LETTER X.

Rarefaction and Elaſticity of the Air.

I HAVE remarked, that air is a fluid, about 800 times more ſubtile than water; ſo that could water, without being reduced to vapour, be expanded over a ſpace ſo many times greater, and could become of conſequence ſo many times more ſubtile, it would be of a ſimilar conſiſtence with the air which we breathe. But air has a property which water has not, that of ſuffering compreſſion into a ſmaller ſpace, and of being proportionably condenſed, as I demonſtrated in the preceding letter. And we diſcover in air another property no leſs remarkable: it is capable of being expanded over a greater ſpace, and thus rendered ſtill more ſubtile. This operation is called the rarefaction of air.

You have only to take, as before, a tube A B C D, (*plate* I. *fig.* 3.) at the bottom of which A C, let there be a ſmall aperture O, ſo that, on introducing the piſton as far as to F, the air may eſcape by that aperture without being condenſed. The air which now occupies the cavity A C E F, will then be in it's natural ſtate; let the aperture O be cloſely ſtopped. On drawing back the piſton, the air will gradually expand through the greater ſpace, ſo that when the piſton is brought back to the point G, the ſpace C G being double the ſpace C F, the ſame air which was contained in the ſpace A C E F, will fill a ſpace twice as great; it will be of courſe only half as denſe, or, which is the ſame thing, twice as rare. If you draw back the piſton to the point H, the ſpace C H being four times as great as the ſpace C F, the air will become four times as rare as it was at firſt, as it is then expanded over a ſpace four times as great. And could the piſton be drawn back till the ſpace became 1000 times as great, the air would ſtill equally expand through that ſpace, and conſequently become 1000 times as rare. Here then, likewiſe, air differs eſſentially from water: for if the cavity A C E F were filled with water, to no purpoſe would you draw back the piſton; the water would continue to occupy the ſame ſpace as at firſt, and the reſt would remain empty. Hence we ſee that the air poſſeſſes an intrinſic power of expanding itſelf more and more, which it exerts not only when it is condenſed, but

but alſo when rarefied. In whatever ſtate of condenſation or rarefaction the air may be, it makes unremitting efforts to extend itſelf over a larger ſpace, and is continually expanding ſo long as it meets no obſtacle. This property is called the elaſticity of air; and it has been demonſtrated by experiments which I ſhall preſently deſcribe, that this elaſtic power is in proportion to the denſity; in other words, the more the air is condenſed the greater are it's efforts to expand itſelf; and the more rarefied it is, the feebler are thoſe efforts. It will be demanded, perhaps, why the air now in my chamber does not make it's eſcape by the door; being endowed with an expanſibility continually impelling it to occupy a greater ſpace? The anſwer is obvious. This would infallibly happen, did not the external air make equal efforts to extend itſelf; but the efforts of the air of the chamber to get out, and that of the external air to preſs in, being equal, they balance each other, and remain in a ſtate of reſt. Had the external air accidentally acquired a greater degree of denſity, that is, more elaſticity, it would in part force it's way into the chamber, where the air being compreſſed, would likewiſe acquire a greater degree of elaſticity; this current would accordingly laſt till the elaſticity of the internal became equal to that of the external air. And ſhould the air of the chamber ſuddenly become more denſe, and it's elaſticity greater than that of the external air, it would force it's way out, and it's denſity gradually diminiſhing, it's elaſticity too would diminiſh, till it became equal to the external air;

the current would then ceafe, and the air in the chamber would be in equilibrium with the external. Free air, then, is in a ftate of reft only when it has the fame degree of elafticity with that which furrounds it; and as foon as that of the one tract becomes more or lefs elaftic than the adjoining, the equilibrium can no longer fubfift; but if the elafticity is greater, the air will expand itfelf and flide into fpaces where it is fmaller: and from this motion of the air refults the wind.* Hence it comes to pafs that the elafticity of the air is fometimes greater, fometimes lefs in the fame place; and this variation is indicated by the *barometer*, the defcription of which merits a particular confideration. I confine myfelf, at prefent, to thefe qualities of air, it's condenfation and rarefaction, intreating you to recollect, that the more condenfed it is, the greater power of expanfion or elafticity it acquires; and that on the contrary, the more it is rarefied, the more this quality is diminifhed. Experimental philofophers have invented one machine for rarefying of air, and another for condenfing it: the former is called the air-pump, the latter the condenfer. Thefe machines ferve to perform many curious experiments, with which you are already well acquainted. I referve to myfelf, however, the liberty of recapitu-

* The action of the moon upon the atmofphere, and the motion of the earth's rotation likewife produce regular winds. Chains of mountains fometimes change the direction of winds. Hence we fee that the known caufe of currents of air are of three kinds, ular, accidental, and local.—*F. E.*

lating

lating ſome of them, becauſe they are neceſſary to elucidate and explain the nature and properties of air, which, as they powerfully contribute to the preſervation of animals, and the production of plants, preſs upon us the importance of forming a juſt idea of them.

14th May, 1760.

LETTER XI.

Gravity of the Air.

I HAVE endeavoured to demonſtrate, that the air is a fluid, endowed with the particular property of ſuffering compreſſion into a ſmaller ſpace, and of expanding into a greater, when no obſtacle interpoſes. This property of air, known by the name of ſpring, or elaſticity, from it's reſemblance to a ſpring, which it requires an effort to unbend, and which reſumes it's form as ſoon as the effort ceaſes, is accompanied by another, in common to it with all bodies in general, namely, gravity or weight, in virtue of which all bodies tend toward the centre of the earth, and by which they are under the neceſſity of falling down, unleſs ſupported. The learned are very much divided, and very uncertain, reſpecting the primary and mechanical cauſe of this power, but it's exiſtence is indubitable.* Daily experience evinces

* The properties of matter muſt ultimately be referred to the arbitrary appointment of the Author of Nature. There are cer-

tain

it. We know even the quantity of it, and can meafure it exactly. For the weight of a body is nothing elfe but the power which conftrains it to defcend; and as the weight of every body may be exactly meafured, we know perfectly well the effect of gravity, though the caufe, or that invifible power which acts upon all bodies, forcing them to defcend, may be abfolutely unknown to us. It follows, that the more matter any body contains, the heavier it is. Gold and lead are heavier than wood or a feather, as they contain more matter in the fame bulk, or in the fame extent. But as air is a very fubtile and thin fubftance, and it's gravity of confequence very little, this property ufually efcapes our fenfes. Experiments, however, may be made, capable of producing full conviction that it poffeffes gravity. You have feen how the air may be rarefied in a veffel or a tube; and by means of the air-pump, this rarefaction may be carried fo far, as almoft entirely to exhauft the air, and to leave the receiver fenfibly a vacuum. Or you may take a tube A B C D, (*plate* I. *fig.* 4.) into which you introduce the pifton, fo as perfectly to touch the bottom, and to leave no air between the wo furfaces. To perform the experiment with re advantage, let there be at the bottom of the

a principles at which the prudent philofopher will choofe to , left, by pufhing his refearches too far, he involve himfelf in ter obfcurity. Thofe who attempted to account for gravity mechanical impulfe, committed an egregious overfight; for the ftill recurs, What produces this impulfe? No metaphyhas ever done fo much fervice to philofophy as Mr. irable effay on "Neceffary Connexion."—*E. E.*

tube

tube a little aperture G, through which the air may escape, as the piston is pushed forward. Let the aperture then be closely stopped, that not a particle of air may be included between the piston and the bottom of the tube. Having made this arrangement, draw back the piston, and the external air not being able to force it's way into the tube, there will remain between the bottom of the tube and the piston, a perfect vacuum, which may be increased at pleasure, by continuing to draw back the piston. You may thus exclude the air contained in a vessel; and such vessel, reduced to a vacuum, being tried in accurate scales, will be found to weigh less than when filled with air. Hence we deduce this very important conclusion, That the air contained in an empty vessel increases it's weight, and that the air itself possesses gravity. Were the vessel large enough to contain 800 pounds weight of water, we might discover by this experiment, that the body of air which fills it would weigh nearly one pound. Hence we conclude, that air is 800 times lighter than water. I must be understood as speaking of the common air which surrounds us, and which we breathe; for you know that with the assistance of art, air may be compressed by forcing it into a smaller space, and it's gravity thereby increased. Were the vessel which I have mentioned, to be filled with air compressed to twice the consistency of common air, it would weigh two pounds more than when empty. Were it filled with air 800 times more compressed than common air, it would weigh 800 pounds more than when empty, that

LETTER XII.

Of the Atmoſphere, and the Barometer.

HAVING demonſtrated that air is a fluid, elaſtic, and poſſeſſed of gravity, I proceed to remark, that the earth is ſurrounded on all ſides by this fluid, and that the ſpace which it fills is called the atmoſphere. It would be abſolutely impoſſible for a perfect vacuum to exiſt on any part of the earth's ſurface; for the air of the adjoining regions, compreſſed by the weight of the ſuperior air, and making inceſſant efforts to dilate, would force itſelf into the empty ſpace and fill it. The atmoſphere, therefore, occupies the whole region which ſurrounds the earth; the inferior air is continually compreſſed by the weight of the ſuperior air, and that until the degree of elaſticity which reſults from this compreſſion, is able to form an equilibrium to the compreſſing power. Then, although this air is compreſſed only in a downward direction, it produces, in virtue of it's elaſticity, efforts to expand itſelf not only downwards, but ſideways alſo. For this reaſon, the air in a chamber is as much compreſſed as the external, which appeared a paradox to certain philoſophers. For they reaſoned thus: In a chamber, the inferior air is compreſſed only by the ſmall quantity of ſuperior air included in that chamber, whereas the external air is compreſſed by the weight of the whole atmoſphere, the height of which is immenſe. But

the

the difficulty is at once removed, by the property which air poſſeſſes, of expanding itſelf when compreſſed in all directions. Now the air in the chamber is at firſt reduced, by the external air, to the ſame degree of compreſſion and elaſticity with itſelf; hence, whether I am in my chamber, or in the open air, I feel the ſame compreſſion; being always underſtood, that I mean at the ſame height, or at the ſame diſtance from the centre of the earth. For I have already remarked, that on getting to the ſummit of a high tower, or of a lofty mountain, the compreſſion of the air is leſs, becauſe the weight of the ſuperior air is then diminiſhed. Various phenomena confirm this ſtate of the compreſſion of the air.

Take, for inſtance, (*plate* I. *fig.* 5.) a tube A B, cloſe at the end A, and having filled it with water, or any other fluid, invert it, ſo that the open end B may be undermoſt, and you will find that the fluid does not run out. The elaſticity of the air acting at B, in oppoſition to the fluid, ſupports it in the tube. But if you make an aperture into the tube at A, the fluid immediately deſcends: the air which is admitted by the aperture acts then from above, by it's preſſure upon the water, and forces it downward; which demonſtrates, that while the tube was cloſe at top, it was the external air which ſupported the water in it. And were ſuch a tube to be placed in a receiver, from which the air was extracted by the air-pump, the fluid would inſtantly deſcend. The ancients, to whom this property of air was unknown, alleged, nature ſupported the water in the tube, from the

the horror which it has of a vacuum. For, ſaid they, were the fluid to deſcend, there muſt be a vacuum at the upper end of the tube, as the air could find no admiſſion into it. According to them, therefore, it was the horror of a vacuum which kept the fluid ſuſpended in the tube. It is now demonſtrated, that it is the force of the air which ſupports the weight of the fluid in the tube; and as this force has a determinate quantity, the effect cannot exceed a certain limit.

It is found by experiment, that if the tube A B is more than 33 feet in length, water will no longer remain ſuſpended in it, but will run out till it comes to the height of 33 feet; the ſpace left a-top will, of courſe, be a real vacuum. The force of the air then cannot ſupport water in the tube at more than the height of 33 feet; and as the ſame force ſupports the whole atmoſphere, it is concluded, that a column of the atmoſphere is of equal weight, the baſis being equal with a column of water 33 feet high. If, inſtead of water, you were to uſe mercury, which is 14 times heavier, the force of the air could ſupport it in the tube at the height of only 28 inches; and if you go beyond that, the mercury deſcends, till it's height correſponds to the preſſure of the atmoſphere, leaving the ſpace a-top in the tube a vacuum. Such a tube cloſe above, and open below, being filled with mercury, forms the inſtrument called the *Barometer*, by means of which it has been diſcovered, that the atmoſphere is not always of equal gravity. For it's real gravity is aſcertained by the barometer, from the height

height of the mercury, which, as it rises or falls, indicates that the denſity of the air, or the preſſure of the atmoſphere, is increaſing or diminiſhing.

20th May, 1760.

LETTER XIII.

Of Wind-Guns, and the Compreſſion of Air in Gun-Powder.

HAVING explained that remarkable property of air which is denominated compreſſibility, by means of which it is reducible into a ſmaller ſpace, we are enabled to give an account of ſeveral productions of both nature and art. I ſhall begin with an explanation of the wind-gun, though I have no doubt but you are well acquainted with that inſtrument. It's conſtruction is ſimilar to that of the common fuſil; but inſtead of powder, we employ condenſed air to diſcharge the bullet.

In order to comprehend the proceſs of this operation, it muſt be obſerved, that air can be compreſſed only by a force proportional to the degree of condenſation which you wiſh to obtain; in this ſtate, it ſtrives to extend itſelf, and the efforts which it makes are preciſely equal to the force neceſſary to reduce it to the ſize which it actually occupies. The more, then, that the air is condenſed, the more violent are ...fforts to dilate; and if the air is raiſed to a den...ice as great as when it is free, which is the caſe

caſe when we reduce it to half the ſpace which it occupies in it's natural ſtate, the force with which it endeavours to expand is equal to the preſſure of a column of water 33 feet high. Figure to yourſelf a great caſk of this height, filled with water; this fluid will, undoubtedly, make a ſtrong preſſure on the bottom of the veſſel. If you make a hole in it near the bottom, the water will force itſelf out with conſiderable violence: and on ſtopping the aperture with your finger, you will be abundantly ſenſible of this preſſure of the water. The bottom of the caſk ſuſtains throughout a ſimilar preſſure. Now a veſſel containing air twice as denſe as that of the atmoſphere, muſt undergo preciſely ſuch a preſſure, and if it were not ſufficiently ſtrong to ſuſtain it, would burſt. The ſides, then, of this veſſel muſt be as ſtrong as the bottom of the caſk I have mentioned. If in the ſame veſſel the air were three times as denſe as common air, the force with which it would act upon the ſides muſt be increaſed in the proportion of one more, and would be the ſame which is ſuſtained by the bottom of a caſk full of water, of 66 feet in height. You will eaſily conceive that this force muſt be very great, and that it muſt go on increaſing in the ſame ratio, according to the different degrees of condenſation of the air. This being laid down, there is, at the bottom of the air-gun, a cavity ſtrongly fortified on all ſides, into which the air is more and more compreſſed, in order to reduce it to as high a degree of denſity as the force employed for

 that

that purpoſe can admit. The air confined in this cavity will thereby acquire a prodigious power to force itſelf out: and if an aperture is made, it will fly off with a velocity proportional to that power. Now there is ſuch an aperture which terminates in the cavity of the tube into which the ball is put. It is cloſely ſtopped; but when you wiſh to diſcharge the piece, you open, for an inſtant, the valve which ſhuts it; and the air ruſhing forth, forces out the ball with all the velocity which we remark in ſhooting. Every time you diſcharge, the valve is kept open only a ſingle moment; a certain quantity of air, therefore, and no more, can eſcape, and enough ſtill will remain for ſeveral ſhot. But on diſcharge, it's denſity and correſponding elaſticity diminiſh; and for this reaſon, the latter diſcharges are leſs forcible than the former, till the force is at length entirely exhauſted. Were the valve to remain open any conſiderable time, more air would make it's eſcape, which would all go to waſte; for this force acts upon the ball only while it is in the barrel of the gun; as ſoon as it is ſhot off, it is uſeleſs to leave a paſſage for the air. Hence it appears, that were it poſſible to carry the condenſation of this fluid a great deal farther, you will produce from the wind-gun the ſame effects as from the guns and cannons in common uſe.

The effect of artillery is accordingly founded on the ſame principle. Gunpowder is only a ſubſtance, which contains in it's pores an air extremely condenſed.

denſed.* Nature produces here the ſame operations which we employ for compreſſing the air, but carries the condenſation to a much higher degree. All that is neceſſary is to open the little cavities in which this denſe air is confined, that it may have liberty to eſcape. This is performed by means of fire, which

* Recent experiments have ſomewhat corrected this explanation. Gunpowder, it is well known, is a compoſition of ſulphur, nitre and charcoal. In the detonation of this ſubſtance, the heat puts the ſulphur and charcoal in a condition to diſſolve the acid of the nitre, and to take from it the dephlogiſtic air which enters into it's compoſition. The atmoſpheric *mephites*, which is another principle of this acid, finding itſelf thereby diſengaged, begins to expand, and forms a firſt elaſtic permanent fluid. The firing of the charcoal produces fixed air, which is a ſecond elaſtic permanent fluid. That of the ſulphur produces the vitriolic acid, which is reduced to vapour by the heat of the inflammation *(a)*. Finally, the water which enters into the compoſition of the powder, is likewiſe converted into vapour. Here, then, are four elaſtic fluids produced in the progreſs of this operation. To their expanſion the phenomenon of the exploſion is to be aſcribed. The two laſt, brought back to a liquid ſtate by being cooled, form the ſmoke we perceive after the diſcharge.—*F. E.*

(a) This account of the aeriform fluids, extricated by the inflammation of gun-powder, ſeems very embarraſſed. Sulphur is not an eſſential ingredient in gun-powder; but as it burns at a low heat, it renders the maſs more ſuſceptible of catching fire. The inflammation of gunpowder is preciſely the ſame phenomenon with the detonation of charcoal and nitre. That ſalt is compoſed of vegetable alkali and nitrous acid, which conſiſts of pure and mephitic airs united in a certain proportion. By means of the heat at firſt applied, and then rapidly evolved during the proceſs of inflammation, the nitrous acid is decompoſed; it's mephitic air is expelled, while it's pure air, combining with the charcoal, forms fixed air, which is alſo diſcharged. It appears from experiment, that this aerial compound, at the inſtant of it's extrication, has upwards of five hundred times the elaſticity of common air.—*E. E.*

burſts open theſe little envelopes: the air then ſuddenly flies off, with incredible velocity, and forces before it bullets and balls in a manner entirely ſimilar to that which we have remarked in the caſe of the wind-gun, but with much greater impetuoſity. Here, then, are two very ſurpriſing effects produced from the condenſation of air, with this ſingle difference, that in the one, it is the work of art; and in the other, that of nature. We ſee therefore in this, as in every thing elſe, how infinitely the operations of human ſkill are ſurpaſſed by thoſe of nature.

24th May, 1760.

LETTER XIV.

The Effect produced by the Heat and Cold on all Bodies, and of the Pyrometer and Thermometer.

BESIDE the properties already mentioned, air has another very remarkable quality, in common to it with all bodies, not excepting ſuch as are ſolid; I mean the change produced on it by heat and cold. It is obſervable, in general, that all bodies, being heated, dilate or increaſe in ſize. A bar of iron made very hot, is ſomewhat longer and thicker than when it is cold. There is an inſtrument called the *Pyrometer*, which accurately indicates the ſlighteſt differences of length or ſhortneſs, that a bar of iron undergoes, to which it is applied. You know that in in a watch, ſome of the wheels move very ſlowly, though they communicate motion to others which revolve with conſiderable rapidity. By a ſimilar mechaniſm it is poſſible, from a change almoſt imperceptible, to produce one very conſiderable, as is the caſe of the pyrometer, which I have juſt mentioned. It has an index, which runs over a very conſiderable ſpace, on the ſlighteſt change produced in the length of the body on which the experiment is made. On applying this inſtrument to a bar of iron, or any other metal, placed over a burning lamp, the index is immediately put in motion, and ſhews that the bar is becoming longer; and, as the heat increaſes, the bar likewiſe increaſes in length. But on extinguiſhing the lamp, and the bar growing cold again, the index moves in a contrary direction, and thereby ſhews that the bar is growing ſhorter. The difference, however, is ſo ſlight, that, without the help of this inſtrument, it would be difficult to perceive it. Yet this variation is abundantly perceptible in the motion of pendulum time-pieces. The uſe of the pendulum is to regulate the motion. If you lengthen it, the clock goes ſlower, and if you ſhorten it, the clock goes faſter. Now it is remarked, that in very hot weather all clocks loſe time, and proportionably gain it in very cold weather; which clearly demonſtrates, that the pendulum is lengthened or ſhortened, according to the temperature of the air.

All bodies undergo this alteration, but the quantity differs greatly, according to the nature of the ſubſtance of which they are compoſed. In fluids, eſpecially, this variability is very perceptible. To aſcertain it, take a glaſs tube, B C, *(plate* I. *fig.* 6*)* joined at the end B to a hollow ball A, and let it be filled with any liquor you pleaſe up to M. On heating the ball A, the liquor will riſe from M toward C: when it becomes cold again, the liquor will fall toward B. This clearly proves that the ſame liquid occupies a greater ſpace when it is heated, and a ſmaller when cold. It is likewiſe clear, that this variation muſt be more perceptible, when the ball is large, and the tube narrow. For, if the whole maſs of liquor increaſes or diminiſhes by a thouſandth part, that thouſandth part will occupy, in the tube, a ſpace great in proportion to it's narrowneſs. Such an inſtrument then is exceedingly proper to indicate to us the different degrees of heat and cold; for if the liquor riſes or falls, it is a certain indication that the heat is increaſing or diminiſhing. This inſtrument is called the *Thermometer*, which points out the changes that take place in the temperature of the air, and of the bodies which ſurround us. It muſt not be confounded with the barometer, whoſe uſe is to indicate the gravity of the air, or rather the force with which it is compreſſed. This caution is the more neceſſary, that the barometer and thermometer have a conſiderable reſemblance: being both glaſs tubes filled with mercury; but their conſtruction, and the principles on which they are founded are entirely different. This quality of body, extenſion by heat,

heat, and contraction by cold, belongs likewise, in a very superior degree, to air. I shall explain it at greater length in my next letter.*

27th May, 1760.

LETTER XV.

Changes produced in the Atmosphere by Heat and Cold.

HEAT and cold produce the same effect on air, as on every other body. Air is rarefied by heat, and condensed by cold. From what I have said of the elasticity of air, you easily perceive, that a certain quantity of this fluid is not determined to occupy only a certain space, as all other bodies are; but by

* There are three kinds of thermometers in use at present, that of Reaumur is adopted in France, Switzerland, and Italy; that of Celsius in Sweden and Denmark. In both of these, the scale commences at the freezing point; but the interval, between that and the boiling point, is divided, in the former, into 80 parts, and the latter, into 100. Farenheit's thermometer is used in Britain and Holland; the freezing point is marked on it 32, and the boiling 212, the interval containing 180 degrees. The freezing point is very nearly permanent, but the boiling point depends on the pressure of the atmosphere, and near the surface of the earth it varies one degree and six-tenths for every inch of variation in the height of the barometer. Water has been heated in a close vessel to such a degree, as to melt lead and tin; and in the receiver of an air-pump, it may be converted into vapour, at the ordinary temperature of the air. Hence the reason why water boils so quickly on the summit of lofty mountains. The boiling point would be at 172° on the heights of the Andes.—*E. E.*

it's nature, it has a perpetual tendency to dilate, and actually does expand itſelf, as long as it meets no obſtacle.

This property of air is denominated elaſticity. When this fluid is confined in a veſſel, it makes efforts in every direction to burſt it; and theſe efforts are greater or leſs in proportion to it's condenſation. Hence we come to this concluſion, that the elaſticity of air is in exact proportion to it's denſity; ſo that when it's denſity is doubled, it's elaſticity is likewiſe doubled; and that, in general, a certain degree of elaſticity correſponds to a proportional degree of denſity. It muſt be remarked, however, that this takes place no longer than while the air preſerves the ſame degree of heat. Whenever it becomes hotter, it acquires greater power of expanſion than what correſponded to it's denſity; and cold produces the oppoſite effect, by diminiſhing it's expanſive power. In order then to determine the elaſticity of a maſs of air, it is not ſufficient to know it's denſity; you muſt likewiſe know it's degree of heat. In order to ſet this in a clear light. Let us ſuppoſe two chambers cloſely ſhut on all ſides, but united by a door of communication; and that the heat in both is equal. In order to this the air in both chambers muſt have the ſame degree of denſity. For were the air more denſe, and conſequently more elaſtic, in the one than in the other, part of it would eſcape from the one, and force it's way into the other, till the denſity in both were the ſame. But let us ſuppoſe that one of the chambers has become hotter than the other, the air thereby acquiring

acquiring a greater elafticity, would of courfe force itfelf into the other, and reduce that which it found there into a fmaller fpace, till the elafticity in both chambers was brought to the fame degree. During this change there will be a current of air, through the door, from the chamber which is more, into that which is lefs heated; and when the equilibrium is reftored, the air will be more rarefied in the warm apartment, and more condenfed in the cold; and yet the elafticity of both will be the fame. From this it clearly follows, that two maffes of air of different denfity, may have the fame elafticity, when the one is hotter than the other; and this circumftance taken into confideration, it may happen, that with the fame degree of denfity, they may be endowed with different degrees of elafticity.

What I have faid of two chambers may be applied to two countries; and hence it may be concluded, that when one country becomes warmer than the other, there muft of neceffity be a current of air from the one to the other: and from this refults the wind.

Here, then, is one fruitful fource of winds, though there are perhaps others, which confift in the different degrees of heat, which prevail in different regions of the earth; and it is demonftrable, that the whole air which furrounds the earth could not be in a ftate of reft, unlefs that, univerfally, at equal heights, there were found the fame degree, not only of denfity, but likewife of heat. And fhould it happen that there were no wind over the whole furface of the earth, it might with certainty be concluded, that

the

the air would likewife be every where equally denfe and warm at equal heights. Now as this never happens, there muft of neceffity always be winds, at leaft in fome regions. But thefe winds are, for the moft part, to be met with only on the furface of the earth; and the higher you rife, the lefs violent winds are. Winds are hardly perceptible at the fummit of very high mountains;* there perpetual tranquillity reigns; from which it is impoffible to doubt, that at confiderable elevations, the air is always in a ftate of reft. Hence it follows, that in regions remarkably elevated, there univerfally prevails all over the earth, the fame degree of denfity and heat; for were it hotter in one place than in another, the air could not be in a ftate of reft. And, as there is no wind in thefe elevated regions, it muft neceffarily follow, that the degree of heat there muft be univerfally and always the fame; which is a very furprizing paradox, confidering the great variations of heat and cold which we feel on the furface of the earth, during the courfe of a year, and even of one day; without taking into the account the difference of climate, that is, the intolerable heats felt under the equator, and the

* This does not appear perfectly exact. A perpetual current of wind, from eaft to weft, muft be produced by the motion of the earth's rotation. It refults, likewife, from M. d'Alembert's theory of winds. Befides, the attraction of the moon, which is capable of raifing the waters of the globe, undoubtedly communicates fome motion to the atmofphere. Here, then, we have fuperior currents. When aëroftation is carried to perfection, it will, perhaps, pro-ve us fatisfying information refpecting this article of meteoro-.—*F. E.*

dreadful

dreadful cold which ever prevails toward the poles of the earth. Experience itſelf, however, confirms the truth of this aſtoniſhing fact. The ſnow and ice remain equally, ſummer and winter, on the mountains of Switzerland, and are equally unchangeable on the Cordeliers, lofty mountains of Peru, ſituated under the very equator, and where there perpetually reigns, nevertheleſs, a cold as exceſſive as that of the polar regions. The height of theſe mountains is not a German mile,* or 24,000 feet. From this it may be, with confidence, concluded, that were it poſſible for us to aſcend to the height of 24,000 feet, above the earth, we ſhould always and univerſally meet with the ſame degree of cold, and that cold exceſſively ſevere.† We ſhould remark there no ſenſible difference during either ſummer or winter, under the equator, or near the poles. At this height, and ſtill higher, the ſtate of the atmoſphere is univerſally, and at all ſeaſons, the ſame; and the variations of heat and cold take place near the ſurface of the earth alone. It is only in theſe inferior regions, that the effect of the rays of the ſun becomes perceptible. You have, undoubtedly, ſome curioſity to know the reaſon of this. It ſhall be the ſubject of the following letter.

31ſt May, 1760.

* About 4 3-5ths miles, Engliſh.

† M. Charles, in his aërial voyage of the 1ſt Dec. 1783, felt this change of temperature in a very ſenſible manner; for then, on the ſurface of the earth, the fluid in the thermometer ſtood at 7° above the freezing point, and after about 10 minutes of aſcenſion, it had fallen to 5° below it.—*F. E.*

LETTER

LETTER XVI.

The Cold, felt on high Mountains and at great Depths, accounted for.

IT appears very ſurpriſing, that we ſhould feel the ſame degree of cold in all regions, after we have riſen to a certain height, ſay 24,000 feet; conſidering that the variations with reſpect to heat, on the earth, not only in different climates, but in the ſame country, at different ſeaſons of the year, are ſo perceptible. This variety, which takes place at the ſurface of the globe, is undoubtedly occaſioned by the ſun. It appears, at firſt ſight, that his influence muſt be the ſame above and below, eſpecially when we reflect, that a height of 24,000 feet, or a mile, though very great with reſpect to us, and even far beyond the height of the loftieſt mountains, is a mere nothing, compared to the diſtance of the ſun, which is about thirty millions of miles.* This is, therefore, a very important difficulty, which we muſt endeavour to ſolve. For this purpoſe I begin with remarking, that the rays of the ſun do not communicate heat to any bodies, but ſuch as do not grant them a free paſſage. You know that bodies, through which we can diſcern objects, are denominated *tranſparent*, *pellucid*, and *diaphonous*. Theſe bodies are glaſs, cryſtal,

* Mr. Euler always means German miles, of 4000 fathoms each, or ſomewhat under 4 3-5ths miles Engliſh.—*E. E.*

diamond,

diamond, water, and ſeveral other liquids, though ſome are more or leſs tranſparent than others. One of theſe tranſparent bodies being expoſed to the ſun, is not heated to ſuch a degree as a body not tranſparent, as wood, iron, &c. Bodies not tranſparent are denominated *opaque*. A burning-glaſs, for example, by tranſmitting the rays of the ſun, ſets on fire opaque bodies, while the glaſs itſelf is not ſenſibly heated. Water expoſed to the ſun becomes ſomewhat warm, only becauſe it is not perfectly tranſparent; when we ſee it conſiderably heated by the ſun at the brink of rivers, it is becauſe the bottom, being an opaque body, is heated by the rays which the water tranſmits. Now, every heated body communicates that heat to all adjoining bodies; the water accordingly derives heat from the bottom. If the water be very deep, ſo that the rays cannot penetrate to the bottom, it has no perceptible heat, though the ſun bears upon it.

As air is a very tranſparent body to a much higher degree than glaſs or water, it follows that it cannot be heated by the ſun, becauſe the rays are freely tranſmitted through it. The heat which we frequently feel in the air is communicated to it by opaque bodies, which the rays of the ſun have heated; and were it poſſible to annihilate all theſe bodies, the air would ſcarcely undergo any change in it's temperature by the rays of the ſun: expoſed to it or not it would be equally cold. But the atmoſphere is not perfectly tranſparent: it is even ſometimes ſo loaded with vapours, that it loſes almoſt entirely it's

tranſparency,

tranſparency, and preſents only a thick fog. When the air is in this ſtate, the rays of the ſun have a more powerful influence upon it, and heat it immediately.

But theſe vapours riſe to no great height; at the height of 24,000 feet, and beyond, the air is ſo ſubtile and ſo pure, that it is perfectly tranſparent; and for this reaſon the rays of the ſun cannot immediately produce any effect upon it. This air is likewiſe too remote from terreſtrial bodies to receive a communication of heat from them; they act only upon ſuch as are adjacent. Hence you will eaſily perceive that the rays of the ſun cannot produce any effect in regions of the air very much elevated above the ſurface of the earth; and that the ſame degree of cold muſt always and univerſally prevail in ſuch regions, as the ſun has no influence there, and as the heat of terreſtrial bodies cannot be communicated ſo far. This is nearly the caſe on the ſummit of very high mountains, where it is always much colder than on plains and in vallies.*

* There are clouds, however, above theſe mountains, and in almoſt as great a quantity as above the plains, which is demonſtrated by the ſnows which cover the higheſt ſummits. There are few naturaliſts who have not been ſurpriſed by clouds in their excurſions upon the mountains. The heat that is felt when ſuch clouds are formed muſt be attributed almoſt entirely to the tranſmiſſion of the water which found itſelf diſſolved in the air, under the form of elaſtic fluid, to a liquid ſtate. The heat of the ſolar rays, intercepted by the cloud, can produce no change in the in-. emperature, as it would have been tranſmitted from the -F. E.

The

The city of Quito, in Peru, is almoſt under the equator, and were we to form our judgment from it's ſituation on the globe, we would ſuppoſe it oppreſſed with intolerable heat; the air, however, is abundantly temperate, and differs very little from that of Paris. Quito is ſituated at a great height above the real ſurface of the earth. In going to it from the ſea ſhore you have to aſcend for ſeveral days; it is accordingly built in an elevation equal to that of our higheſt mountains, though ſurrounded by others ſtill much higher, called the Cordeliers. This laſt circumſtance would afford a reaſon for thinking that the air there muſt be as hot as at the ſurface of the earth, as it is contiguous on all ſides to opaque bodies, on which the rays of the ſun fall. The objection is ſolid; and no ſolution can be given but this. That the air at Quito, being very elevated, muſt be much more ſubtile, and of leſs gravity than with us; and the barometer, which always ſtands conſiderably lower, inconteſtably proves it.

Air of ſuch a quality is not ſo ſuſceptible of heat as common air, as it muſt contain leſs vapour and other particles which uſually float in the atmoſphere; and we know by experience that air very much loaded is proportionably ſuſceptible of heat. I muſt here ſubjoin another phenomenon no leſs ſurpriſing: In very deep pits, and lower ſtill, if it were ſtill poſſible to deſcend, the ſame degree of heat always and univerſally prevails, and nearly for the ſame reaſon. As the rays of the ſun exert their influence only on the ſurface of the earth, and as the heat which they there

there excite communicates itſelf up and down, this effect at very great depths is almoſt imperceptible. The ſame thing holds reſpecting conſiderable heights. This elucidation will, I flatter myſelf, prove ſatisfactory.*

3d June, 1760.

LETTER

* The reaſon which Profeſſor Euler aſſigns for the cold that prevails in the higher regions of the atmoſphere ſeems plauſible, but will not ſtand an accurate examination. Light is much impaired in it's paſſage through the atmoſphere, and the heat communicated is in every caſe proportional to the quantity of abſorption. It appears, from ſome ingenious experiments of M. Bouguer, that we receive only four-fifths of the rays of a vertical ſun; and when that luminary approaches the horizon, the portion of his light which reaches the ſurface of the earth, is much ſmaller. Thus at an elevation of 20 degrees it is one half; at that of 10 degrees one third; and at that of five degrees one-eighth. Hence the ſun-beams are moſt powerful on the ſummits of lofty mountains, for they ſuffer the greateſt diminution in paſſing through the denſe air of the lower regions. If the air derived it's heat from the ſurface of the earth, thoſe countries would be warmeſt which enjoyed the greateſt quantity of ſun-ſhine. The Britiſh iſlands are ſhrouded in clouds nine months of the year; yet our climate is milder than that of the ſame parallel on the Continent, where the ſky is generally ſerene. The elevated town of Quito, expoſed to a brilliant ſun, enjoys a temperate air; while the Peruvian plains, ſhaded with fleecy clouds, are parched with heat. Were the reaſoning in the text to be admitted, we ſhould conclude that the tops of mountains are warmer than their baſes. To ſay that air, much rarefied, is not ſuſceptible of heat, is a very extraordinary aſſertion, ſince we are acquainted with no ſubſtance whatever that may not be heated. Beſides, a more intenſe cold may be artificially produced than what prevails in the lofty regions of the atmoſphere. We muſt recur to other principles for the true ſolution

LETTER XVII.

Of Light, and the Syſtems of Deſcartes and Newton.

HAVING ſpoken of the rays of the ſun, which are the focus of all the heat and light that we enjoy, you will undoubtedly aſk, What are theſe rays? This is beyond queſtion one of the moſt important inquiries in phyſics, as from it an infinite number

ſolution of the fact. It is indifferent what portion of the air firſt receives the heat; the effect depends entirely on the nature of it's diſtribution. If the atmoſphere were of an uniform denſity throughout, the heat would at all heights be likewiſe the ſame. But as the denſity varies according to the altitude, the diſtribution of heat is affected by that circumſtance, and follows a certain correſponding law. I would gladly develope the principles from which this theory is deduced, but the popular nature of the preſent treatiſe forbids all abſtract diſcuſſion. I ſhall therefore content myſelf with giving a table of the diminution of heat at different altitudes.

Altitude in feet.	Diminution of heat, in degrees, of Farenheit,
3,000	— — — — 12°
6,000	— — — — 24½
9,000	— — — — 38
12,000	— — — — 53
15,000	— — — — 68½
18,000	— — — — 86½
21,000	— — — — 94½

The diminution of heat, on the aſcent, is not quite ſo great in extenſive continents; for the intercourſe between the rare and the denſe portions of the atmoſphere is, in this caſe, neceſſarily ſlow, and the heat, which is principally formed at the ſurface, will only be partially diſperſed.

number of phenomena is derived. Every thing that refpects light, and that renders objects vifible, is clofely connected with this inquiry. The ancient philofophers feem to have taken little intereft in the folution of it. They contented themfelves with faying that the fun is endowed with the quality of fhining, of giving heat and light. But is it not worth while to inquire, Wherein does this quality confift? Do certain portions, inconceivably fmall, of the fun himfelf, or of his fubftance, come down to

It is a common miftake to fuppofe, that the fame heat obtains, at a certain depth, in every part of the globe. The fact is, that heat, originally derived from the fun, is communicated very flowly to the matter below the furface, which, therefore, does not feel the viciffitude of feafons, but retains the average temperature of the climate for many ages. Hence the utility of examining the heat of fprings, which is the fame with that of the fubftances through which they flow. The following table exhibits the average heat of places on the level of the fea, computed by the celebrated aftronomer, Profeffor Meyer, for every five degrees of latitude.

Latitude.	Average Temperature.	Latitude.	Average Temperature.
0	84°	50	53½°
5	83½	55	49
10	82½	60	45
[illegible]	80½	65	41½
	78	70	38
	74½	75	35½
	71	80	33½
	67	85	32½
	62½	90	32
	58		

comparing this table with the preceding [illegible] it is [illegible] for any latitude, the altitude of the curv[illegible] of [illegible] re the average temperature is 32 [illegible] E. [illegible].

us? Or is the transmission similar to the sound of bell, which the ear receives? though no part of th substance of the bell be separated from it, as I observ ed in explaining the propagation and perception of sound.

Descartes, the first of modern philosophers, maintained this last opinion, and having filled the whole universe with a subtile matter composed of small globules, which he calls the second element, he supposes that the sun is in a state of continual agitation, which he transmits to these globules, and pretends that they again communicate their motion in an instant to every part of the universe. But since it has been discovered that the rays of the sun do not reach us instantaneously, and that they take eight minutes to fly through that immense distance,* the opinion of *Descartes*, which laboured beside under other difficulties, has been given up.

The great *Newton* afterwards embraced the former ystem, and maintained that the luminous rays are ally separated from the body of the sun, and the rticles of light thence emitted with that inconceiv le velocity which brings them down to us in about ht minutes. This opinion, which is that of most dern philosophers, particularly the English, is

This important fact was discovered toward the end of the last ry by Roemer, a learned Dane, of the ancient Academy of es. It was an inequality of the satellites of Jupiter which to it. The cause of this aberration, discovered by Brad- 728, incontestably demonstrates the same phenomenon.—

 called

called *the ſyſtem of emanation;* it being imagined that rays emanate from the ſun and other luminous bodies, as water emanates or ſprings from a fountain.

This opinion appears at firſt ſight very bold, and irreconcilcable to reaſon. For were the ſun emitting continually, and in all directions, ſuch floods of luminous matter, with a velocity ſo prodigious, he muſt ſpeedily be exhauſted, or at leaſt ſome alteration muſt, after the lapſe of ſo many ages, be perceptible. This, however, is contradicted by obſervation. It cannot be a matter of doubt, that a fountain which ſhould emit ſtreams of water in all directions, would be exhauſted in proportion to the velocity of the emiſſion; much more the ſun, whoſe rays are emitted with a velocity ſo inconceivable. Let the particles of which rays of light are formed be ſuppoſed as ſubtile as you pleaſe, nothing will be gained: the ſyſtem will ever remain equally untenable. It cannot be affirmed that this emanation is not made in all directions: for, wherever you are placed, the whole ſun is viſible, which proves inconteſtably, that rays from every point of the ſun are emitted toward the ſpot which you occupy. The caſe is very different from that of a fountain, which ſhould emit ſtreams of water in all directions. For one point in the fountain could furniſh only one ſtream directed to a particular ſpot, but every point of the ſun's ſurface muſt emit an infinite number, diffuſing themſelves in all directions. This circumſtance alone infinitely increaſes the expenditure of luminous matter, which would have to make.

Another

Another difficulty, and which appears equally insuperable, is, that the ſun is not the only body which emits rays, but that all the ſtars have the ſame quality: and as every where the rays of the ſun muſt be croſſing the rays of the ſtars, their colliſion muſt be violent in the extreme. How muſt their direction be changed by ſuch colliſion! This colliſion muſt take place with reſpect to all luminous bodies, viſible at the ſame time. Each, however, appears diſtinctly, without ſuffering the ſlighteſt derangement from any other: a certain proof that many rays may paſs through the ſame point, without diſturbing each other, which ſeems irreconcileable to the ſyſtem of emanation. Let two fountains be ſet a playing upon each other, and you will immediately perceive their different ſtreams diſturbed and confounded: it muſt of conſequence be concluded, that the motion of the rays of light is very eſſentially different from that of a *jet d'eau*, and in general from all ſubſtances forcibly emitted.

Conſidering afterwards tranſparent bodies through which rays are freely tranſmitted in all directions, the ſupporters of this ſyſtem are under the neceſſity of affirming that theſe bodies contain pores, diſpoſed in ſtraight lines, which iſſue from every point of the ſurface, and proceed in all directions; it being inconceivable how there could be any line through which a ray of the ſun might be tranſmitted with ſuch amazing velocity, and even without the ſlighteſt colliſion. Here then are bodies wonderfully porous, which have the appearance, neverthelefs, of being extremely folid.

Finally, in order to enjoy vifion, the rays muft enter into the eye, and penetrate it's fubftance with the fame velocity. All thefe difficulties, taken together, will, I doubt not, fufficiently convince you, that the fyftem of emanation has in no refpect a foundation in nature; and you will certainly be aftonifhed that it could have been conceived by fo great a man, and embraced by fo many enlightened philofophers. But it is long fince Cicero remarked, that nothing fo abfurd can be imagined as to find no fupporter among philofophers. For my part, I am too little a philofopher to adopt the opinion in queftion.

7th June, 1760,

LETTER XVIII.

Difficulties attending the Syftem of Emanation.

HOWEVER ftrange the doctrine of the celebrated *Newton* may appear, that rays proceed from the fun by a continual emanation, it has, however, been fo generally received, that it requires an effort of courage to call it in queftion. What has chiefly contributed to this is, no doubt, the high reputation [illegible] great Englifh philofopher, who firft difcovered [illegible] laws of the motions of the heavenly bodies; and

and it is this very discovery which led him to the system of emanation.

Descartes, in order to support his theory, was under the necessity of filling the whole space of the heavens with a subtile matter, through which all the celestial bodies move at perfect liberty. But it is well known that if a body moves in air, it must meet with a certain degree of resistance; from which *Newton* concluded, that however subtile the matter of the heavens may be supposed, the planets must encounter some resistance in their motions. But, said he, this motion is not subject to any resistance: the immense space of the heavens, therefore, contains no matter. A perfect vacuum, then, universally prevails. This is one of the leading doctrines of the Newtonian philosophy, that the immensity of the universe contains no matter in the spaces not occupied by the heavenly bodies. This being laid down, there is between the sun and us, or at least from the sun down to the atmosphere of the earth, an absolute vacuum. In truth, the farther we ascend, the more subtile we find the air to be; from whence it would apparently follow, that at length the air would be entirely lost. If the space between the sun and the earth be an absolute vacuum, it is impossible that the rays should reach us in the way of communication, as the sound of a bell is transmitted by means of the air. For if the air, intervening between the bell and our ear, were to be annihilated, we should absolutely hear nothing, let the bell be struck ever so violently.

. . ...; . ftablifhed, then, a perfect vacuum between . . ..nly bodies, there remains no other opinion . :.. adopted but that of emanation; which obliged . ...n to maintain, that the fun and all other luminous bodies emit rays which are always particles, infinitely fmall, of their mafs, darted from them with incredible force. It muft be fuch to a very high degree, in order to imprefs on rays of light that inconceivable velocity with which they come from the fun to us in the fpace of eight minutes. But let us fee whether this theory be confiftent with *Newton's* leading doctrine, which requires an abfolute vacuum in the heavens, that the planets may encounter no manner of refiftance to their motions. You muft conclude, on a moment's reflection, that the fpace in which the heavenly bodies revolve, inftead of remaining a vacuum, muft be filled with the rays, not only of the fun, but likewife of all the other ftars which are continually paffing through it from every quarter, and in all directions, with incredible rapidity. The heavenly bodies which traverfe thefe fpaces, inftead of encountering a vacuum, will meet with the matter of luminous rays in a terrible agitation, which muft difturb thefe bodies in their motions much more than if it were in a ftate of reft.

Thus *Newton*, apprehenfive left a fubtile matter, fuch as *Defcartes* imagined, fhould difturb the motions of the planets, had recourfe to a very ftrange expedient, and quite contradictory to his own intent. ... on his hypothefis, the planets muft be ex... ...derangement infinitely more confiderable.

I have

I have already ſubmitted to you ſeveral other inſuperable objections to the ſyſtem of emanation; and we have now ſeen that the principal and indeed the only reaſon which could induce *Newton* to adopt it, is ſo ſelf-contradictory as wholly to overturn it. All theſe conſiderations united, leave us no room to heſitate about the rejection of this ſtrange ſyſtem of the emanation of light, however reſpectable the authority of the philoſpher who invented it.

Newton was, without doubt, one of the greateſt geniuſes that ever exiſted. His profound knowledge, and his acute penetration into the moſt hidden myſteries of nature, will be a juſt object of admiration to the preſent, and to every future age. But the errors of this great man ſhould ſerve to admoniſh us of the weakneſs of the human underſtanding, which, after having ſoared to the greateſt poſſible heights, is in danger of plunging into manifeſt contradiction.*

10th June, 1760.

LETTER

* The *pious* as well as learned and ingenious Author, in the firſt edition of theſe Letters, ſubjoined to this reflection on *Newton's* doctrine of emanation a ſeries of reflections which do equal honour to his underſtanding and his heart. The French Editor, for what reaſon it does not appear, has thought proper to ſuppreſs them. Could he imagine a philoſophical work diſgraced by a modeſt and not unſeaſonable infuſion of religious ſentiment? Be how it will, the Engliſh Editor felt himſelf obliged to reſtore the paſſage, in preſenting the too long neglected Euler to the Britiſh nation.—— It follows:

" If we are liable to weakneſſes and inconſiſtencies ſo humiliat-
" ing,

LETTER XIX.

A different Syſtem reſpecting the Nature of Rays and of Light, propoſed.

YOU have ſeen that the ſyſtem of the emanation of the rays of light labours under inſuperable difficulties, and that the doctrine of a vacuum for the heavenly bodies to range in, is equally untenable; as the rays of light would completely fill it. Two things, then, muſt be admitted: firſt, the ſpace through which the heavenly bodies move is filled with a ſubtile matter; ſecondly, rays are not an actual emanation from the ſun and other luminous bodies, in virtue of which part of their ſubſtance is

" ing, in our reſearches into the phenomena of this viſible world, " which lies open to the examination of our ſenſes, how wretched " muſt we have been had God left us to ourſelves with reſpect to " things inviſible, and which concern our eternal ſalvation? On " this important article a Revelation was abſolutely neceſſary to " us; and we ought to avail ourſelves of it with the moſt pro- " found veneration. When it preſents to us things which may " appear inconceivable, we have but to reflect on the imperfection " of human underſtanding, which is ſo apt to be miſled, even as " to ſenſible objects. Whenever I hear a pretended Freethinker " inveighing againſt the truths of religion, and even ſneering at " it with the moſt arrogant ſelf-ſufficiency, I ſay to myſelf: poor " weak mortal, how inexpreſſibly more noble and ſublime are the " ſubjects which you treat ſo lightly, than thoſe reſpecting which " the great *Newton* was ſo groſsly miſtaken! I could wiſh your " Highneſs to keep this reflection ever in remembrance: occaſions " making it occur but too frequently."—*E. E.*

violently

violently emitted from them, according to the doctrine of *Newton.**

That ſubtile matter which fills the whole ſpace in which the heavenly bodies revolve, is called *Ether*. Of it's extreme ſubtilty no doubt can be entertained. In order to form an idea of it, we have only to attend to the nature of air, which, though extremely ſubtile, even on the ſurface of the earth, becomes more and more ſo as we aſcend; and entirely ceaſes, if I may uſe the expreſſion, when it comes to be loſt in the ether. The ether, then, is likewiſe a fluid as the air is, but incomparably finer and more ſubtile, as we are aſſured that the heavenly bodies revolve

* The materiality of light is ſupported by the moſt convincing proofs that phyſics can afford. The inflection, refraction, and reflection of it's rays, ſhew manifeſtly that, like other bodies, it is ſubject to attraction and repulſion; and the ſimple application of the doctrine of forces not only explains ſatisfactorily the phenomena, but aſſigns the preciſe effects with the moſt perfect accuracy. The difficulties which ſeem to attend the theory of emanation vaniſh on a cloſe inveſtigation. So vaſt is the tenuity of light, that it utterly exceeds the powers of conception. The moſt delicate inſtrument has never been certainly put in motion by the impulſe of the accumulated ſun-beams. Even on the moſt unfavourable ſuppoſition it appears from calculation that, in the ſpace of 385,130,000 Egyptian years (of 360 days) the ſun would loſe only the $\frac{1}{1,217,420\text{th}}$ of his bulk, from the continual efflux of light. On the ſame hypotheſis the force impreſſed upon the earth by each emiſſion is ſuch as would make it recede only the two billionth part of an inch in an hundred ſeconds, and it's effect, during a ſeries of ages, would therefore be altogether inſenſible. After ſtating numbers of a magnitude ſo enormous, it would be ſuperfluous to conſider the quantity of ſtroke which the eye receives.

freely

freely through it, without meeting any perceptible reſiſtance. It is alſo without doubt poſſeſſed of elaſticity, by means of which it has a tendency to expand itſelf in all directions, and to penetrate into ſpaces where there would otherwiſe be a vacuum; ſo that if by ſome accident the ether were forced out of any ſpace, the ſurrounding fluid would inſtantly ruſh in and fill it again.

In virtue of this elaſticity, the ether is to be found not only in the regions which are above our atmoſphere, but it penetrates the atmoſphere univerſally, inſinuates itſelf by the pores of all bodies, and paſſes irreſiſtibly through them. Were you, by the help of the air-pump, to exhauſt the air from a receiver, you muſt not imagine that you have produced an abſolute vacuum; for the ether, forcing itſelf through the pores of the receiver, completely fills it in an inſtant. Having filled a glaſs tube of the proper length with mercury, and immerged it, when inverted, in the ciſtern, in order to make a barometer, it might be ſuppoſed that the part of the tube which is higher than the mercury is a vacuum, becauſe the air is completely excluded, as it cannot penetrate the pores of glaſs: but this vacuum which is apparent only, is undoubtedly ſupplied by the ether, inſinuating itſelf without the ſmalleſt difficulty.

It is by this ſubtilty and elaſticity of ether that I ſhall by and by explain to you the remarkable phenomena of electricity. It is even highly probable ether has an elaſticity much ſuperior to that of ad that many of the phenomena of nature are produced

produced by means of it. For my own part I have no doubt that the compreſſion of the air in gunpowder is the effect of the elaſtic power of ether. And as we know by experiment that the air in it is condenſed almoſt 1000 times more than common air, and that in this ſtate it's elaſticity is likewiſe 1000 times greater, the elaſticity of the ether muſt in this caſe be ſo too, and conſequently 1000 times greater than that of common air. We ſhall then have a juſt idea of ether, in conſidering it as a fluid in many reſpects ſimilar to air, with this difference, that ether is incomparably more ſubtile and more elaſtic.*

Having ſeen then that the air, by theſe very qualities, is in a proper ſtate for receiving the agitations or ſhakings of ſonorous bodies, and to diffuſe them in all directions, as we find in the propagation of ſound, it is very natural to ſuppoſe that ether may in the ſame circumſtances likewiſe receive agitations in the ſame manner, and tranſmit them to the greateſt diſtances.† As the vibrations of the air produce *ſound*,

* This, perhaps, is what in modern times they denominate the matter of heat.—*F. E.*

† The hypotheſis of an ether is a clumſy attempt to preclude the neceſſity of admitting *action at a diſtance*. It has been a received maxim, that cauſe and effect muſt exiſt in the ſame place; but the leaſt reflection will convince us that, were this principle true, there could never be any communication of motion. The difficulty is really the ſame, to conceive action exerted at the diſtance of the thouſandth part of an inch, as at that of a thouſand miles. The particles of matter are far from being in mutual contact, otherwiſe

found, What will be the effect of thofe of ether? You will undoubtedly guefs at once *light*. It appears in truth abundantly certain, that light is with refpect to ether, what found is with refpect to air; and that the rays of light are nothing elfe but the fhakings or vibrations tranfmitted by the ether, as found confifts in the fhakings or vibrations tranfmitted by the air.

The fun, then, lofes nothing of his fubftance in this cafe, any more than a bell in vibrating; and, in adopting this fyftem, there is no reafon to apprehend that the mafs of this orb fhould ever fuffer any diminution. What I have faid of the fun muft alfo be extended to all luminous bodies, fuch as fire, a wax taper, a candle, &c.

It will, undoubtedly, be objected, that thefe terreftrial luminaries evidently wafte, and that unlefs they are continually fed and kept up, they will be fpeedily extinguifhed; that confequently the fun muft in time be wafted away, and that the parallel of a bell is not accurate. But it is to be confidered, that thefe fires, befides their light, throw out fmoke, and a great deal of exhalation, which muft be carefully diftinguifhed from the rays of light. Now the fmoke and exhalation evidently occafion a confiderable diminution, which muft not be imputed

wife all bodies would have the fame denfity, and be totally incapable of compreffion. Were the univerfe an abfolute *plenum*, motion and animation would for ever ceafe. To afcribe to ether an extreme rarity, and at the fame time to affert that it fills all fpace, and pervades all bodies, is a contradiction in terms. But the hypothefis is fo big with abfurdity, that it deferves not a particular examination. *See note, p.* 41.—*E. E.*

to

to the rays of light; for were it poſſible to ſeparate them from the ſmoke and other exhalations, the luminous quality alone would occaſion no expenditure. Mercury may, by means of art, be rendered luminous, as you have probably ſeen, and that without any diminution of it's ſubſtance, which proves that light alone produces no waſte of luminous bodies. Thus though the ſun illuminates the whole world by his rays, he loſes nothing of his own ſubſtance, his light being only the effect of a certain agitation, or violent concuſſion of his minute particles, communicated to the adjoining ether, and thence tranſmitted in all directions by means of this fluid to the remoteſt diſtances, as a bell when ſtruck communicates it's own agitation to the circumambient air. The more we conſider this parallel between ſonorous and luminous bodies, the more we ſhall find it conformable to nature, and juſtifiable by experience; whereas the more we attempt to reconcile the phenomena of nature to the ſyſtem of emanation, the more difficulties we encounter.

14th June, 1760.

LETTER XX.

Of the Propagation of Light.

THE propagation of light in the ether is produced in a manner ſimilar to that of ſound in the air; and juſt as the vibrations occaſioned in the particles of air conſtitutes ſound, in like manner the vibration of of the particles of ether conſtitutes light or luminous rays; ſo that *light is nothing elſe but an agitation or concuſſion of the particles of ether*, which is every where to be found on account of it's extreme ſubtilty, in virtue of which it penetrates all bodies.

Theſe bodies, however, modify the rays of light in many different ways, by tranſmitting or ſtopping the propagation of the concuſſions. Of this I ſhall treat at large in the ſequel. I confine myſelf at preſent to the propagation of rays in the ether itſelf, which fills the immenſe ſpace in which the heavenly bodies revolve. There the propagation takes place in perfect liberty. The firſt thing which here preſents itſelf to the mind is the prodigious velocity of the rays of light, which is about 900,000 times more rapid than that of ſound, though this laſt travels no leſs than 1000 feet in a ſecond.

This amazing velocity would be ſufficient of itſelf to overturn the ſyſtem of emanation; but in that which I am attempting to eſtabliſh, it is a natural conſequence, from the principles laid down, as I hope to demonſtrate. They are the ſame with thoſe on which is founded the propagation of ſound in the air, and this depends at once on it's denſity and elaſticity. It is evident that if the denſity of air were diminiſhed, ſound would be accelerated, and if the elaſticity of the air were increaſed, the ſame thing would happen. If the denſity of the air diminiſhed, and it's elaſticity increaſed at once, we ſhould have a ... d reaſon for the increaſe of the velocity of ... us conceive, then, the denſity of the air diminiſhed,

diminiſhed, and it's elaſticity increaſed, till it's denſity and elaſticity became equal to thoſe of ether, and we ſhould then no longer be ſurpriſed that the velocity of ſound had become many thouſands of times greater than it actually is. For you will be pleaſed to remember, that, according to the firſt ideas we formed of ether, this fluid muſt be inconceivably rarer, and more elaſtic than air. Now both of theſe qualities equally contribute to accelerate the velocity of vibrations. From this explanation, the prodigious velocity of light is ſo far from preſenting any thing irreconcileable to reaſon, that it rather perfectly harmonizes with the principles laid down; and the parallel between light and ſound is in this reſpect ſo firmly eſtabliſhed, that we may confidently maintain, That if air ſhould become as ſubtile and as elaſtic as ether, the velocity of ſound would become as rapid as that of light.

The ſubtlity of ether, then, and it's great elaſticity, are the reaſon which we aſſign for the prodigious velocity of the motion of light; and ſo long as the ether preſerves this ſame degree of ſubtlity and elaſticity, this velocity muſt continue the ſame. Now it cannot be doubted that the ether has, through the whole univerſe, the ſame ſubtlity and the ſame elaſticity. For were the ether leſs elaſtic in one place than in another, it would force itſelf into it till the equilibrium was perfectly reſtored. The light of the ſtars, therefore, moves with as great velocity as that of the ſun; and as the ſtars are at a much greater diſtance from us than the ſun, a much greater quantity of time is requiſite to tranſmit their rays to us. However great the diſtance of the ſun may appear, whoſe rays, nevertheleſs, reach the ſurface of our globe in eight minutes, the fixed ſtar neareſt to us is at leaſt 400,000 times more diſtant than the ſun: a ray of light iſſuing from that ſtar will employ then 400,000 times eight minutes in travelling to us, that is 53,333 hours, or 2,222 days, or ſix years nearly.

It is then upwards of ſix years ſince the rays of light iſſued from that fixed ſtar, the leaſt remote and probably the moſt brilliant, in order to render it viſible to us, and theſe rays have employed a period ſo conſiderable to fly through the ſpace which ſeparates us from that ſtar. Were God juſt now to create a new fixed ſtar, at the ſame diſtance, it could not become viſible to us till more than ſix years had elapſed, as it's rays require that length of time to travel this diſtance. Had one been created at the beginning of the world a thouſand times more diſtant than that which I have mentioned, it could not yet be viſible to us, however brilliant, as 6000 years are not yet elapſed ſince the Creation. The firſt preacher of the court of Brunſwick, Mr. Jeruſalem, has happily introduced this thought in one of his ſermons; the paſſage runs thus:

" Raiſe your thoughts from the earth which you " inhabit to all the bodies of the vaſt univerſe, which " are ſo far above you: launch into the immenſity " of ſpace which intervenes between the moſt re- " mote which your eyes are able to diſcover, and " thoſe whoſe light, from the moment of creation

" till

"till now, has not as yet, perhaps, come down to us. "The immenſity of the kingdom of God juſtifies "this repreſentation." (Sermon *on the Heavens, and Eternal Beatitude.)*

I flatter myſelf that theſe reflections will excite a deſire of further inſtruction reſpecting the ſyſtem of light, from which is derived the theory of colours, and of viſion.

17th June, 1760.

LETTER XXI.

Digreſſion, on the Diſtances of the Heavenly Bodies, and on the Nature of the Sun, and his Rays.

THE obſervations which I have been making reſpecting the time which the light of the ſtars employs in making it's progreſs down to us, convey a ſtriking idea of the extent and greatneſs of the univerſe. The velocity of ſound, which flies through the ſpace of 1000 feet in a ſecond, furniſhes us with nearly the firſt ſtandard of meaſurement. It is about 200 times more rapid than the pace of a man who is a good walker. Now the velocity of the rays of light is 900,000 times ſtill more rapid than that of ſound: theſe rays accordingly perform, every ſecond, a courſe of 900 millions of feet, or 37,500 German miles.*

What aſtoniſhing velocity! Yet the neareſt fixed

* More than 170,000 miles Engliſh.—*E. E.*

ſtar is ſo remote, that it's rays, notwithſtanding this prodigious velocity, would take more than ſix years in deſcending to us. And were it poſſible for a great noiſe, ſuch as that of the firing of a cannon, iſſuing from that ſtar, to be conveyed to our ears, it would require a period of 5,400,000 years to reach us. And this is applicable only to thoſe ſtars which are the moſt brilliant, and are probably neareſt to us. Thoſe which appear the ſmalleſt are, very probably, ten times ſtill farther remote, and more. A whole century then, at leaſt, muſt elapſe, before the rays of theſe ſtars could poſſibly reach us. How prodigious muſt that diſtance be, which cannot be paſſed through in leſs than 100 years, by a velocity which flies at the rate of 37,500 German miles every ſecond!

Were, then, one of theſe ſtars to be juſt now annihilated, or eclipſed only, we ſhould ſtill continue to ſee it for 100 years to come, as the laſt rays which it emitted could not reach us in leſs time.

The generality of mankind is very far from having any thing like juſt ideas reſpecting the vaſt extent of the univerſe. Many conſider it as a work of little importance, which chance alone might have produced. But what muſt be the aſtoniſhment of one who reflects, on obſerving, that all theſe immenſe bodies are arranged with the moſt conſummate wiſdom, and that the more knowledge we acquire on the ſubject, though it muſt ever be very imperfect, the more we muſt be diſpoſed to admire their order and magnificence?

eturn to the great luminous bodies, and particularly

cularly the ſun, which is the principal ſource of the light and heat which we enjoy on the earth. It will be aſked, in the firſt place, Wherein conſiſts the light which the ſun is inceſſantly diffuſing through the whole univerſe, without ever ſuffering the ſmalleſt diminution? The anſwer is obvious, according to the ſyſtem which I have been endeavouring to eſtabliſh. But that of emanation furniſhes no ſatisfactory ſolution. The whole univerſe being filled with that extremely ſubtile and elaſtic fluid, which is called ether, we muſt ſuppoſe, in all the parts of the ſun, an inceſſant agitation, by which every particle is in a conſtant motion of vibration, and this, by communicating itſelf to the circumambient ether, excites in that fluid a ſimilar agitation, and is thence tranſmitted to regions the moſt remote, with the rapidity which I have been deſcribing.

And, to keep up the parallel between ſound and light, the ſun would be in a ſtate ſimilar to that of a bell which ſhould be ringing continually. The particles of the ſun muſt, conſequently, be kept in this inceſſant agitation, to produce in the ether the undulations which we call rays of light. But it is ſtill no eaſy matter to explain, by what power this agitation in the particles of the ſun is conſtantly kept up, as we obſerve, that a match does not long continue burning, but preſently goes out, unleſs it be ſupplied with combuſtible matter. But it muſt be remarked, that as the ſun is a maſs many thouſand times greater than our whole globe, if it is once thoroughly inflamed, it may continue in that ſtate for ſeveral ages, without ſuffering any ſenſible diminution. Beſides, the caſe is not the ſame with the ſun and our fires and candles, a conſiderable part of whoſe ſubſtance is diſſipated in ſmoke and exhalations, from which a real waſte reſults. Whereas, though perhaps ſome particles may be forced from the ſun in form of ſmoke, they cannot remove to a great diſtance, but ſpeedily fall back into it's maſs, ſo that there cannot be any real expenditure, to occaſion a diminution of his ſubſtance.*

The only thing of which we are ſtill ignorant reſpecting this ſubject, is, the power which inceſſantly maintains all the particles of the ſun in this agitation. But as it contains nothing inconſiſtent with good ſenſe, and as we are under the neceſſity of acknowledging our ignorance of many other things much leſs remote than the ſun, we ought to be ſatiſfied, if our ideas are not involved in contradiction.

21ſt June, 1760.

* The Author is evidently embarraſſed in his explanation of the continual inflammation of the ſun. And though he has ſaid above, that the ſyſtem of emanation was untenable, on account of the frequent and unavoidable colliſion of rays proceeding from different luminous bodies, which muſt diſturb, and even obſtruct the viſion of ſeveral of theſe bodies at once, as he has not explained how two ſounds may be heard at the ſame time, a ſimilar objection might be made to his ſyſtem, which is analogous to the phenomena of ſound.—*F. E.*

LETTER XXII.

Elucidations on the Nature of luminous Bodies, and their Difference from opaque Bodies illumined.

THE ſun being a luminous body, whoſe rays are univerſally diffuſed in all directions, you can no longer be at a loſs to account for this wonderful phenomenon, which conſiſts in the ſhaking, or vibration, with which all the particles of the ſun are agitated. The parallel of a bell lends conſiderable aſſiſtance toward the explanation of this fact. But it is obvious, that the vibrations produced by light, muſt be much more vehement and rapid than thoſe produced by ſound, ether being incomparably more ſubtile than air. A feeble agitation not being capable of ſhaking the air ſo as to produce ſound in it, that of a bell, and of all other ſonorous bodies, are too feeble relatively to ether, to produce in it the vibration which conſtitutes light.

You will recollect, that in order to excite a perceptible ſound, more than 30, and leſs than 7552 vibrations muſt be produced in a ſecond; the air being too ſubtile to admit of a ſenſible effect from a ſound conſiſting of leſs than 30 vibrations in a ſecond, but not ſufficiently ſo to receive one of more than 7552 vibrations in the ſecond. A note higher than this could not be at all heard. It is the ſame with reſpect to ether; 7552 vibrations, produced in a ſecond, could not poſſibly act upon it, becauſe of it's greater fubtilty. It requires vibrations much more frequent. An agitation fo rapid could not take place but in the minuteft particles of bodies which elude our fenfes. The light of the fun, then, is produced by a very violent agitation, which affects all his infinitely minute particles, each of which muft fhake many thoufands of times every fecond.

It is a fimilar agitation which likewife produces the light of the fixed ftars, and of all fires, fuch as candles, tapers, torches, &c. which give us light, and fupply the place of the fun during the night. On attentively obferving the flame of a wax-light, you will eafily perceive that, in the minuteft particles, there is a conftant and furprizing agitation; and I do not apprehend that my fyftem is liable on this fide to any contradiction, while that of Newton requires a moft enormous agitation, capable of launching the minuteft particles with the velocity of 37,500* German miles in a fecond.

This, then, is the explanation of the nature of bodies luminous of themfelves: for there are luminous bodies which are not fo immediately, fuch as the moon and the planets, which are fimilar to our globe. We fee the moon only when, and in as far as, fhe is illuminated by the fun; and this is the cafe of all terreftrial bodies, fires excepted, which have a light of their own. But other bodies, which are denominated opaque, become vifible to us only when they are illuminated by fome luminous body.

In a very dark night, or in an apartment, fo clofely

* Upwards of 170,000 Englifh miles.

fhut

ſhut on every ſide, that no light can find admiſſion, to no purpoſe will you turn your eyes toward the objects which ſurround you in the dark: you perceive nothing. But the moment a taper is introduced, you immediately ſee, not the taper only, but the other bodies which were before inviſible. We have here, then, a very eſſential difference between luminous and opaque bodies. I have already employed the term *opaque* to denote bodies which are not tranſparent; but it comes to almoſt the ſame thing, and we muſt accommodate ourſelves to the common modes of expreſſion, though they are not perfectly accurate. Luminous bodies are viſible by their own light, and never affect our organs of ſight more than when the darkneſs is otherwiſe moſt profound. Thoſe which I here denominate opaque, are rendered viſible to us only by means of a light that is foreign to them. We perceive them not while they remain in darkneſs; but as ſoon as they are expoſed to a luminous body, whoſe rays ſtrike upon them, they become viſible; and they diſappear the moment that foreign light is withdrawn. It is not even neceſſary, that the rays of a luminous body ſhould fall upon them immediately; another opaque body, when well illuminated, produces nearly the ſame effect, but in a feebler manner.

The moon is an excellent inſtance. We know that the moon is an opaque body; but when ſhe is illuminated by the ſun, and we ſee her during the night, ſhe diffuſes a feeble light over all opaque bodies, and renders viſible to us thoſe which we could not have perceived

perceived without her aſſiſtance. Placed in the day time in an apartment, whoſe aſpect is toward the north, and into which, of courſe, the rays of the ſun cannot enter, it is, however, perfectly clear, and I am able to diſtinguiſh every object. What can be the cauſe of this clearneſs, but that the whole heaven is illuminated by the ſun? What we call the azure ſky, and beſides, the walls oppoſite to my apartment, and the other ſurrounding objects, are likewiſe illuminated, either immediately by the ſun, or mediately by other opaque bodies, expoſed to the action of that focus of light; and the light of all theſe opaque, but illuminated, bodies, as far as it has admiſſion into my apartment, renders it luminous, and that in proportion as the windows are high, wide, and well placed. The glaſs is little or no interruption, being, as I have already remarked, a tranſparent body, which freely tranſmits the rays of light.

When I completely exclude the light from the apartment, by cloſing the window-ſhutters, I am reduced to a ſtate of darkneſs, and diſcern no object, unleſs I call for a candle. Here, then, is an eſſential difference between luminous and opaque bodies; and likewiſe a very ſtriking reſemblance, namely, that opaque bodies, when illuminated, illuminate other opaque bodies, and produce, in this reſpect, nearly the ſame effect as bodies luminous of themſelves.

[illegible]e explanation of this phenomenon has, hitherto, [illegible]reatly perplexed philoſophers, but, I flatter myſelf, [illegible] my ſolution of it has been clear and ſatisfactory.

June, 1760.

LETTER

LETTER XXIII.

How Opaque Bodies become visible. Newton's System, of the Reflection of Rays, proposed.

BEFORE I attempt an explanation of the phenomenon of opaque bodies becoming visible when they are illuminated, it must be remarked, in general, that we see nothing but by means of the rays which enter into our eyes. When we look at any object whatever, rays issuing from every point of that object, and entering into the eye, paint upon it, if I may use the expression, the image of the object. This is not mere conjecture, but may be demonstrated by experiment. Take, for example, the eye of an ox, or of any animal recently killed, and, after having uncovered the bottom, you find all the objects which were before it painted there. As often then as we see an object, the image of it is painted on the bottom of our eyes; and this is produced by the rays which proceed from the object to us. I shall afterwards take occasion to go into a more minute detail on the subject of vision, and explain in what manner the images of objects are formed on the bottom of the eye: let this general remark suffice for the present.

As we see opaque bodies only when they are illuminated, this is a proof, that there must proceed from every point of these bodies rays of light which subsist only during the illumination. The moment they are placed in the dark these rays disappear. They are not proper then to opaque bodies; their origin muſt be ſought in the manner in which other bodies illuminate them. And this is the great queſtion, How illumination alone is capable of producing rays on opaque bodies, or of putting them in nearly the ſame ſtate as luminous bodies are, which, by an agitation in their minuteſt particles, produce rays of light?

The great *Newton*, and other philoſophers, who have examined the ſubject, aſſign *reflection* as the cauſe of this phenomenon: it is, therefore, of the higheſt importance, that you ſhould form a juſt idea of what is called reflection.

This name is given to the repulſion of one body ſtruck againſt another, as may be ſeen in the game of billiards. When the ball is ſtruck againſt the cuſhion or ledge of the billiard table, it recoils again; and this retrograde motion is termed reflection. It is neceſſary, here, to attend to a diſtinction between two caſes. Let us ſuppoſe A B (*plate* I. *fig.* 7.) to be the ledge of a billiard table. The firſt caſe is this: When you play the ball D perpendicularly againſt the ledge, in the direction of D C, perpendicular to A B, and, conſequently, the adjacent angles A C D, and B C D, are right angles: in this caſe, the ball will be driven back, or reflected, in the ſame line D C. The other caſe is, when the ball is played obliquely againſt the ledge, ſuppoſe in the line E C, forming, with A B, an acute angle A C E, this is called the angle of incidence. The ball will, in this caſe, be repelled from the ledge, in the direction of the line C F, ſo that this line ſhall make, on the other

ſide,

ſide, with the ledge B C, an angle B C F, exactly equal to the angle of incidence A C E. This angle, B C F, formed by the line in which the ball recoils, is called the angle of reflection. And this law always takes place when a body in motion meets with an obſtacle.

A cannon ball, ſhot againſt a wall ſufficiently ſtrong to reſiſt it, is reflected conformably to this law. It extends, in like manner, to ſounds, which are frequently reflected from certain bodies; and you know that this reflection of ſound is called echo. It cannot be doubted, that the ſame thing frequently takes place with reſpect to the rays of light. The objects which we ſee in mirrors, are repreſented to us by the reflection of rays, and every well poliſhed ſurface reflects the rays of light which fall upon it. It is undoubtedly certain, therefore, that there are caſes without number in which the rays that fall on certain bodies are reflected; and philoſophers have thence taken occaſion to maintain, that opaque bodies are rendered viſible by means of reflected rays.

I ſee juſt now houſes, oppoſite to my windows, which are illuminated by the ſun. According, then, to the opinion of thoſe philoſophers, the rays of the ſun falling on the ſurface of theſe houſes, are reflected from them; they enter into my apartment, and render theſe houſes viſible to me. In the ſame manner, if we believe thoſe philoſophers, the moon and the planets become viſible, and theſe are, unqueſtionably, opaque bodies. The rays of the ſun which fall

fall on these bodies, and illuminate the parts which are exposed to them, are reflected, and are thence transmitted to us, just as if the bodies were luminous of themselves. According to this opinion, we see the moon and the planets only by the rays of the sun which they reflect; and you must frequently have heard it affirmed, that the light of the moon is a reflection of the light of the sun. In the same manner, say they, the rays of the sun are reflected by the first opaque bodies which are exposed to them, on other bodies of the same nature, and undergo a series of similar reflections, till they are entirely weakened.

But, however plausible this opinion may at first sight appear, it involves so many absurdities, when closely examined, that it is absolutely untenable, which I hope to demonstrate, as a preparation for the true solution of this phenomenon.

28th June, 1760.

LETTER XXIV.

Examination and Refutation of Newton's System.

I AFFIRM, then, that when we see an opaque body illuminated by the sun, it is impossible to maintain that it reflects luminous rays, and that, by means of such rays, it is rendered visible to us. The example of a mirror, which, undoubtedly, reflects the rays, and is employed to support this opinion, rather

rather confutes it. The mirror, beyond contradiction, ſends back the rays which fall upon it; but when theſe reflected rays enter into our eyes, What do they repreſent? You will readily anſwer, that it is not the mirror, but the objects from which they originally proceeded; and the reflection does nothing elſe, but enable us to ſee theſe objects in another place. Beſides, we ſee thoſe objects, not on the ſurface of the mirror, but rather within it, and it may be ſaid with truth, that the mirror itſelf remains inviſible to us.

But, on looking at an opaque body illuminated by the ſun, we do not ſee in it the image of that glorious orb; we ſee only the ſurface of the bodies, with all the variations to be found on them. We perceive, then, a very eſſential difference between the rays which are reflected from a mirror, and thoſe by means of which opaque bodies are rendered viſible. But there is, beſides, another difference equally palpable in the mirror; for on changing the place of the objects, or our own ſituation, the appearance will always change, and the rays, reflected from the mirror, will continually repreſent to our eyes other images, correſponding to the nature and poſition of the objects, and to the place where we are ſtationed: but, as I have already ſaid, theſe reflected rays never repreſent to us the mirror itſelf.

Now, let a body be illuminated by the ſun, or other bodies, whether luminous or opaque, already illuminated; in whatever manner this body may change it's place, or we change our's relatively to it,

it's

it's appearance is always the fame; we fee always the fame object, and remark in it no change relative to the different circumftances above mentioned. This furnifhes a new proof, that we do not fee opaque bodies by means of the rays reflected from their furface.*

* This can hardly be deemed a fair ftatement. It is true, that opaque bodies are feen only by reflected light, but it by no means follows, that all the incident light is again reflected. Some bodies are, by their conftitution, difpofed to reflect certain kinds of rays the moft freely, and as the reft are abforbed, the peculiar colour predominates. This colour will, therefore, not be the fame, whatever be the quality of the incident light, but will receive an analogous fhade. For the fame reafon, no fubftance reflects only one fpecies of rays. The elective attractions and repulfions, between the particles of light and a body, are moft remarkable at very minute diftances; and hence the colour is prominent when the furface is rough, for the light, fuffering then a partial repulfion only, gains a nearer approach. I cannot imagine how Mr. Euler would explain thefe facts on his own principles.

It is in a polifhed furface only, that the furrounding bodies can be feen by reflection, for diftinct vifion requires the rays, proceeding from different points, to be tranfmitted with regularity. No fubftance is, indeed, perfectly fmooth, but the different repulfions, exerted by the fuperficial particles, may balance each other, and produce an uniform effect, at the diftance where the reflection takes place. Mr. Euler's principles would lead to the conclufion, that polifh is not at all neceffary to a mirror. Echo is formed from furfaces which are very uneven, fince the air is heaped on the obftacle, and the principal reflux of the undulation commences at a fenfible diftance from it. The fame obtains in water, though in a lefs degree; and is, in general, more remarkable, in proportion to the rarefaction of the fluid. How wonder-[illegible]l then, in that refpect, muft ether be, which is fuppofed to be [illegible]ft fubtle of all fluids? We might expect the walls of a [illegible]flect the moft enchanting picture of the landfcape in

An objection will, perhaps, be ftarted, drawn from the dove's neck, and certain kinds of ftuff, which prefent different objects, according as our point of view changes. But this in no refpect weakens my conclufion with regard to ordinary opaque bodies, which are not fubject to this change. The objection only proves, that thefe fingular objects are endowed with certain qualities: as, for example, that their minuter particles are finely polifhed, and that a real reflection takes place, befide the ufual and ordinary manner in which bodies are rendered vifible to us.

Now, it is eafy to comprehend, that this reflection muft be clearly diftinguifhed from the manner in which ordinary opaque bodies are illuminated.

Finally, the rays reflected from a mirror always reprefent to us, likewife, the colours of the bodies from which they originally proceed, and the mirror, which reflects, makes no change in this refpect. One opaque body illuminated by any other body, in whatever manner, always prefents the fame colours; and every body may be faid to have it's proper colour. This circumftance abfolutely overturns the opinion of all thofe who maintain, that we fee opaque bodies by means of the rays which their furface reflects.

Putting together all the reafons which I have now fubmitted to your confideration, there can be no hefitation in pronouncing, that this opinion is totally untenable in philofophy, or rather, in phyfics. I cannot, however, flatter myfelf with the hope, that philofophers, wedded to opinions once adopted,

 fhould

ſhould yield to theſe reaſons. But the naturaliſt, who is more nearly related to the mathematician, will have leſs difficulty in reſigning an opinion, overthrown by reaſons ſo convincing. You will again recollect what Cicero has ſaid on this ſubject: That nothing ſo abſurd can be conceived, as not to be ſupported by ſome philoſopher. In fact, however ſtrange the ſyſtem which I have been refuting may appear to you, it has, hitherto, been propagated and defended with much warmth.

It is impoſſible to ſay, to what a degree the difficulties and contradictions which I have been endeavouring to expoſe, were unknown to, or overlooked by, the partiſans of this ſyſtem. The great *Newton* himſelf ſtrongly felt their force: but as he reſted in a very untenable idea reſpecting the propagation of light, it is not to be wondered at, that he ſhould overlook theſe great difficulties; and, in general, depth of underſtanding does not always prevent a man from falling into abſurdity, in ſupporting an opinion once embraced.

But if this ſyſtem, that opaque bodies are rendered viſible by reflected rays, be falſe, ſay it's partiſans, What then is the true one? They even think it impoſſible to imagine another explanation of this phenomenon. It is, beſides, rather hard and humiliating for a philoſopher to acknowledge ignorance of any ſubject whatever. He would rather maintain the groſſeſt abſurdities; eſpecially if he poſſeſſes the ſecret of involving them in myſterious terms, which no one is capable of comprehending. For in this

caſe,

cafe, the vulgar are the more difpofed to admire the learned; taking it for granted, that what is obfcurity to others, is perfectly clear to them. We ought always to exercife a little miftruft, when very fublime knowledge is pretended to, knowledge too fublime to be rendered intelligible. I hope I fhall be able to explain the phenomenon in queftion, in fuch a way as to remove every difficulty.

1ft July, 1760.

LETTER XXV.

A different Explanation of the Manner in which opaque Bodies illuminated become vifible.

ALL the phenomena of opaque bodies, which I have unfolded in the preceding letter, inconteftably demonftrate, that, when we fee an opaque body illuminated, it is not by rays reflected from it's furface, that it becomes vifible, but becaufe it's minuter particles are in an agitation fimilar to that of the minuter particles of luminous bodies; with this difference, however, that the agitation in opaque bodies is far from being fo ftrong as in bodies luminous of themfelves; for an opaque body, however much illuminated, never makes on the eye an impreffion fo lively as luminous bodies do.

As we fee the opaque bodies themfelves, but by no means the images of the luminous bodies which enlighten them, as muſt be the caſe, if we ſaw them by the reflection of their ſurface; it muſt follow, that the rays emitted by opaque bodies are proper to them, juſt as the rays of a luminous body are peculiar to itſelf. As long as an opaque body is illuminated, the minuter particles of it's ſurface are in a ſtate of agitation proper to produce, in the ether, a motion of vibration, ſuch as is neceſſary for forming rays, and for painting in our eyes the image of the body from which they proceed. For this effect, rays muſt be diffuſed, from every point of the ſurface, in all directions; as experience evidently confirms. For, from whatever ſide we look at an opaque body, we ſee it equally in all it's points; from which it follows, that every point emits rays in all directions. This circumſtance eſſentially diſtinguiſhes theſe rays from ſuch as are reflected, whoſe direction is always determined by that of the rays of incidence; ſo that if the incident rays proceed from one ſingle quarter, ſay the ſun, the reflected rays can follow only one ſingle direction.

It muſt be admitted, then, that when an opaque body is illuminated, all the particles on it's ſurface are put in a certain agitation, which produces rays, as is the caſe with bodies luminous of themſelves. This agitation, likewiſe, is ſtronger, in proportion as the light of the illuminating body is more intenſe. Thus the ſame body, expoſed to the ſun, is agitated much more violently, than if, in a room, it were illuminated only by day-light, or in the night-time, a taper, or by the moon. In the firſt caſe, it's image

image is painted with much greater vivacity on the bottom of the eye, than in the others, eſpecially the laſt; the light of the moon being ſcarcely ſufficient to enable us to diſtinguiſh, or to read, writing of a large ſize. And when the opaque body is conveyed into a cloſe room, or into the dark, nothing is then to be ſeen; a certain proof, that the agitation in it's parts has entirely ceaſed, and that they are now in a ſtate of reſt.

In this, therefore, conſiſts the nature of opaque bodies; their particles are, of themſelves, at reſt, or, at leaſt, deſtitute of the agitation neceſſary to produce light. But theſe ſame particles are ſo diſpoſed, that when illuminated, or ſtruck with rays of light, they are immediately put into a certain agitation, or motion of vibration, proper to produce rays; and the more intenſe the light is, which illuminates theſe bodies, the more violent alſo is this agitation. As long as an opaque body is illuminated, it is in the ſame ſtate as luminous bodies; it's particles are agitated in the ſame manner, and are capable of exciting, of themſelves, rays in the ether; with this difference, that the agitation kept up in luminous bodies by an intrinſic force, ſubſiſts always of itſelf; whereas, in opaque bodies, this agitation is only momentaneous, and produced by the motion of the light which illuminates them.

This explanation is conſiſtent with every phenomenon, and labours under none of the difficulties which determined us to abandon the other, namely, that founded on reflection. Whoever will take the trouble condidly to weigh all theſe reaſons, muſt admit their force. But a very great difficulty ſtill remains to be ſolved: How comes it that illumination, ſimply, can put the particles of an opaque body into an agitation capable of producing rays; and that this agitation ſhould always continue nearly the ſame, whatever difference there may be in the illumination?

I acknowledge, that were it impoſſible to anſwer this queſtion, it would be a great defect in my theory, though it would not amount to a complete refutation, for it contains nothing contradictory. Suppoſing I were ignorant, how illumination produces an agitation in the particles of opaque bodies, this would only prove that the theory is incomplete: and till it is demonſtrated to be abſolutely impoſſible that illumination ſhould produce this effect, my ſyſtem muſt ſubſiſt. But I ſhall endeavour to ſupply this defect, by ſhewing you, how illumination agitates the minuteſt particles of bodies.

5th July, 1760.

LETTER XXVI.

Continuation of the ſame Subject.

I HAVE undertaken to ſhew how the illumination of an opaque body muſt produce in it's minuteſt particles, an agitation proper to excite the rays of light, which render that ſame opaque body viſible.

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The parallel between ſound and light, which differ only in reſpect of leſs and more, light being the ſame thing relatively to ether that ſound is relatively to air, this parallel, I ſay, will enable me to fulfil my engagement. Luminous bodies muſt be compared to muſical inſtruments actually in a ſtate of vibration. It is a matter of indifference whether this be the effect of an intrinſic or of a foreign power: it is ſufficient for my purpoſe that ſound is emitted. Opaque bodies, as long as they are not illuminated, muſt be compared to muſical inſtruments not in uſe, or, if you will, to ſtrings which emit no ſound till they are touched.

The queſtion, then, being transferred from light to ſound, is reſolved into this, Whether it be poſſible for the ſtring of an inſtrument, in a ſtate of reſt, when brought within the ſphere of activity of the ſound of inſtruments in a ſtate of vibration, to receive, in certain circumſtances, ſome agitation, and emit ſound, without being touched? Now this is confirmed by daily experience. If you take the trouble, during a concert, to attend to a particular ſtring in proper tune, you will obſerve that ſtring ſometimes to tremble without having been touched, and it will emit the ſame ſound as if it had been immediately put into vibration. This experiment will ſucceed ſtill better, if the inſtruments ſtrike the ſame note with the ſtring. Conſider attentively the ſtrings of a harpſichord not played upon, while a violin ſtrikes the note *a*, for example, and you will obſerve on the harpſichord the ſtring of the ſame note begin fenfibly to tremble, and even to emit found, without having been touched; fome other chords will likewife be agitated, particularly thofe which are diftant an octave, a fifth, and even a third, provided the inftrument be perfectly in tune.

This phenomenon is well known to muficians, and Mr. Rameau, one of the moft celebrated French compofers, eftablifhed his principles of harmony upon it. He maintains, That octaves, fifths, and thirds, muft be confidered as confonances, becaufe one chord is agitated by the found only of another chord, which is in unifon, or an octave, a fifth, or a third, from the firft. But it muft be admitted that the principles of harmony are fo well eftablifhed by the fimplicity of the relations which founds have to each other, that they have no need of a new confirmation. In truth the phenomenon obferved by Mr. Rameau is a very natural confequence from the principles of harmony.

To render this more fenfible, let us attend to two chords wound up to unifon; on ftriking the one, the other will begin of itfelf to tremble, and will emit it's found. The reafon is abundantly clear; for as a chord communicates to the air by it's trembling a motion of vibration fimilar to it's own, the air, agitated by this motion of vibration, muft reciprocally make the chord tremble, provided that by it's degree of tenfion, it be fufceptible of this motion. The air being put into vibration, ftrikes the chord ever fo little at every reverberation, and the repetition of ftrokes foon impreffes on the chord a fenfible motion;

tion; becaufe the vibrations to which it is difpofed by it's tenfion accord with thofe of the air. If the number of vibrations in the air is the half, or the third, or any other whofe relation is fufficiently fimple, the chord does not receive a new impulfe at every vibration, as in the preceding cafe, but only at the fecond, or the third, or the fourth, which will continue to increafe it's tremulous motion, but lefs than in the firft cafe.

But if the vibrations of the air have not any fimple relation with that which correfponds to the chord, the agitation of that fluid will produce no effect whatever upon it; the vibrations of the chord, if there be any, not correfponding to thofe of the fluid, the following impulfions of the air deftroy for the moft part the effect which the firft might have produced; and this is completely confirmed by experience. Thus when a chord is fhaken by a found, that found muft, in order to it's being perceptible, be precifely the fame with that of the chord. Other founds which have a confonance with that of the chord, will produce, it is true, a fimilar but lefs fenfible effect, and diffonances will produce none at all. This phenomenon takes place not only in mufical ftrings, but in all fonorous bodies whatever. One bell will refound by the noife only of another bell which is in unifon with it, or at the diftance of an octave, a fifth, or a third.

The inftance of a perfon who could break glaffes by his voice farther confirms what I have advanced. When a glafs was prefented to him, by ftriking it he

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found out the note; he then began to ſquall in uniſon, and the glaſs immediately caught the vibration; proceeding to give to his voice all the force he was able, always preſerving the uniſon, the vibration of the glaſs became at length ſo violent, that it broke. It is confirmed, then, by experience that a chord and every other ſonorous body is put into vibration by it's kindred ſound. The ſame phenomenon muſt take place with regard to opaque bodies, of which the minuter particles may be put into a ſtate of agitation by illumination only: which is the queſtion I propoſed to ſolve. The following letter will contain a more ample diſcuſſion of it.

8th July, 1760.

LETTER XXVII.

Concluſion: Clearneſs and Colour of opaque Bodies illumined.

AFTER what has juſt been ſubmitted to your conſideration, you will no longer be ſurpriſed that an opaque body is capable of receiving, from illumination alone, an agitation in it's particles ſimilar to that of the particles of luminous bodies, and which gives them the property of producing rays that render them viſible. Thus the great objection to my explanation of the viſibility of opaque bodies is happily removed; while the other theory, founded on the reflection of rays, has to encounter difficulties

culties which grow in proportion as you attempt to make a more direct application of them to known phenomena.

It is then an eftablifhed truth, that the particles of the furfaces of all bodies which we fee, undergo an agitation fimilar to that of a chord in vibration, but their vibrations are much more rapid; whether it be that this agitation is the effect of an intrinfic force, as in bodies luminous of themfelves, or whether it be produced by the rays of light which fall upon the bodies, that is to fay by illumination, as is the cafe in opaque bodies. It is falfe, then, that the moon being an opaque body, reflects the rays of the fun, and that, by means of this reflected light, fhe is rendered vifible to us, as is commonly underftood. But the rays of the fun, falling on the furface of the moon, excite in it's particles a concuffion, from which refult the rays of the moon; and thefe, entering into our eyes, paint it's image there; it is the fame with the other planets, and with all opaque bodies. This agitation of opaque bodies, when illumined, lafts only during the illumination which is the caufe of it: and as foon as an opaque body ceafes to be illumined, it ceafes to be vifible.

But is it not poffible that this agitation, once impreffed on the particles of an opaque body, may be for fome time kept up, as we fee that a ftring once ftruck, frequently continues to vibrate, though no new impreffion be made upon it? I do not pretend to deny the fact: I even believe that we have examples of it in thofe fubftances which Mr. Margraff prefented to you, and which, once illumined, preferve their light for fome time, though conveyed into a dark room. This, however, is an extraordinary cafe; the vibration of the minuter particles difappearing in all other bodies, with the illumination which occafioned it. But this explanation, which thus far is perfectly felf-confiftent, leads me forward to refearches of ftill greater importance.

'It is undoubtedly certain, that we find an infinite difference between the particles of opaque bodies, according to the variety of the bodies themfelves. Some will be more fufceptible of vibrations, and others lefs, and others finally not at all fo. This difference in bodies occurs but too evidently. One, whofe particles eafily receive the impreffion of the rays which ftrike it, appears to us brilliant; another, on the contrary, in which the rays fcarcely produce any agitation, cannot appear luminous. Among feveral bodies, equally illumined, you will always remark a great difference, fome being more brilliant than others. But there is befides another and a very remarkable difference between the particles of opaque lies, refpecting the number of vibrations which of them, being agitated, will make in a certain

e already obferved, that this number muft alvery great, and that the fubtilty of ether is o require many thoufands in a fecond. But ence here may be endlefs; if fome particles, mple, fhould make 10,000 vibrations in a fend others 11,000, 12,000, 13,000, according

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to the ſmallneſs, the tenſion, and the elaſticity of each, as in the caſe of muſical chords, in which the number of vibrations given in a ſecond may be varied without end; and thence it is I have deduced the difference of high and low notes. As this difference is eſſential in ſounds, and as the ear is affected by it in a manner ſo particular as to render it the foundation of the whole theory of muſic, it cannot be called in queſtion that a ſimilar difference in the frequency of the vibrations of rays of light muſt produce a variation as particular in viſion. If, for example, a particle makes 10,000 vibrations in a ſecond, and produces rays of the ſame ſpecies, the rays which enter into the eye will ſtrike the nerves of that organ 10,000 times in a ſecond; and this effect, as well as the ſenſation, muſt be totally different from thoſe produced by a different particle which ſhould make more or leſs vibrations in a ſecond. There will be in viſion a difference ſimilar to that which the ear perceives on hearing ſharp or flat notes.

You will no doubt be deſirous to know into what this difference in viſion is to be reſolved; and what different ſenſations correſpond to the number, greater or leſs, of the vibrations produced in every body during a ſecond? I have the honour of informing you, That diverſity of colours is occaſioned by this difference; and that difference of colour is to the organ of viſion what ſharp or flat ſounds are to the ear. We have reſolved, therefore, without going after it, the important enquiry reſpecting the nature of colours, which has long employed the attention of the

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body is red, another blue, and another green, the philoſopher could not diſtinguiſh himſelf better than by maintaining the contrary; and he accordingly affirms that there is nothing real in colours, and that there is nothing in bodies relative to them.

The Newtonians make colours to conſiſt in rays only; which they diſtinguiſh into red, yellow, green, blue, and violet; and they tell us that a body appears of ſuch and ſuch a colour when it reflects rays of that ſpecies. Others, to whom this opinion ſeemed abſurd, pretend that colours exiſt only in ourſelves. This is an admirable way to conceal ignorance; the vulgar might otherwiſe believe that the ſcholar was not better acquainted with the nature of colours than themſelves. But you will readily perceive that theſe affected refinements are mere cavil. Every ſimple colour (in order to diſtinguiſh from compound colours) depends on a certain number of vibrations, which are performed in a certain time; ſo that this number of vibrations, made in a ſecond, determines the red colour, another the yellow, another the green, another the blue, and another the violet, which are the ſimple colours repreſented to us in the rainbow.

If, then, the particles of the ſurface of certain bodies are diſpoſed in ſuch a manner, that being agitated, they make in a ſecond as many vibrations as are neceſſary to produce, for example, the red colour, I call ſuch a body red, juſt as the clown does; and I ſee nothing like a reaſon for deviating from the common mode of expreſſion. And rays which

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make ſuch a number of vibrations in a ſecond, may, with equal propriety be denominated red rays; and finally, when the optic nerve is affected by theſe ſame rays, and receives from them a number of impulſions, ſenſibly equal, in a ſecond, we receive the ſenſation of the red colour. Here every thing is clear; and I ſee no neceſſity for introducing dark and myſterious phraſes, which really mean nothing.

The parallel between ſound and light is ſo perfect, that it hits even in the minuteſt circumſtances. When I produced the phenomenon of a muſical chord, which may be excited into vibration by the reſonance only of certain ſounds, you will pleaſe to recollect, that the one which gives the uniſon of the chord in queſtion is the moſt proper to ſhake it, and that other ſounds affect it only in proportion as they are in conſonance with it. It is exactly the ſame as to light and colours; for the different colours correſpond to the different muſical ſounds.

In order to diſplay this phenomenon, which completely confirms my aſſertion, let a dark room be provided; make a ſmall aperture in one of the ſhutters; before which, at ſome diſtance, place a body of a certain colour, ſay a piece of red cloth, ſo that, when it is illumined, it's rays may enter by the aperture into the darkened room. The rays thus tranſmitted into the room will be red, all other light being excluded: and if you hold on the inſide of the room, oppoſite to the aperture, a piece of cloth of the ſame colour, it will be perfectly illumined, and its red colour appear very brilliant; but if you ſubſtitute in it's place a piece of green cloth, it will remain obſcure, and you will hardly ſee any thing of it's colour. If you place on the outſide, before the aperture, a piece of green cloth, that within the chamber will be perfectly illumined by the rays of the firſt, and it's green colour appear very lively. The ſame holds good as to all other colours; and I do not imagine that a more convincing demonſtration of the truth of my ſyſtem can be demanded.

We learn from it, that, in order to illuminate a body of a certain colour, it is neceſſary that the rays which fall upon it ſhould have the ſame colour; thoſe of a different colour not being capable of agitating the particles of that body. This is farther confirmed by a well known experiment. When the ſpirit of wine is ſet on fire in a room, you know that the flame of ſpirit of wine is blue, that it produces only blue rays, and that every perſon in the room appears very pale, their faces, though painted ever ſo deep, have the aſpect of death. The reaſon is evident; the blue rays, not being capable of exciting, or putting in motion the red colour of the face, you ſee on it only a feeble and bluiſh colour: but if one of the company is dreſſed in blue, ſuch dreſs will appear uncommonly brilliant. Now the rays of the ſun, thoſe of a wax taper, or of a common candle, illuminate all bodies almoſt equally; from whence it is concluded, that the rays of the ſun contain all colours at once, though he himſelf appears yellowiſh.

In truth, when you admit into a dark room the rays of all the ſimple colours, red, yellow, green, blue, and violet, in nearly equal quantities, and blend them, they represent a whitish colour. The same experiment is made with various powders, coloured in like manner; on being mixed together, a whitish colour is the result. Hence it is concluded that white is nothing less than a simple colour; but that it is rather a compound of all the simple colours; accordingly we see that white is adapted to the reception of all colours. As to black, it is not properly a colour. Every body is black when it's particles are such that they can receive no motion of vibration, or when it cannot produce rays. The want of rays, therefore, produces the sensation of that colour; and the more particles there are found in any body not susceptible of any motion of vibration on it's surface, the more blackish and obscure it appears.

15th July, 1760.

LETTER XXXIX.

Transparency of Bodies relative to the Transmission of Rays.

I HAVE already remarked, that there are bodies, such as glass, water, and especially air, which transmit the rays of light, and, on account of this property, are denominated pellucid or diaphonous. The ether, however, is the medium in which the rays of light are formed, to which this property most intimately appertains; and other transparent bodies

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are endowed with it only by means of the ether which they contain, and with which they are ſo blended, that the agitations excited by the light may be communicated farther without being interrupted in their progreſs. But this tranſmiſſion is never performed ſo freely as in the pure ether, though it always loſes ſomething; and this in proportion as the tranſparent body is more or leſs groſs. The groſſneſs may even become ſo conſiderable, that the light ſhall be wholly loſt in it; and then the body is no longer tranſparent. Thus, though glaſs be a tranſparent body, a great lump of glaſs ſeveral feet thick is not ſo. In like manner, however pure the water of a river may be, you cannot ſee the bottom where it is very deep, though you can very eaſily where it is ſhallow.*

Tranſparency, then, is a property of bodies rela-

* The common diſtinction of bodies into opaque and tranſparent is inaccurate, for every body has a certain degree of tranſparency. All ſubſtances abſorb light in it's paſſage, but in ſome this abſorption is prodigious, and the quantity of light which penetrates through a certain thickneſs is ſo exceedingly minute as to elude our powers of perception. When the thickneſs is much diminiſhed, the light becomes ſenſible, even in the caſe of bodies that are uſually termed opaque; thus we can ſee through a plate of ivory and a leaf of gold. The different properties of ſubſtances with reſpect to the tranſmiſſion of light, ſeems to depend on the greater or leſs regularity of the diſpoſition of their elementary particles, and on their proximity or diſtance from each other; as theſe circumſtances augment or diminiſh the chance of a ray's paſſing within the limit of abſorption. Whatever be the intenſity of the incident light, the ſame proportion of it is, in a given body, tranſmittted through the ſame thickneſs.—*E. E.*

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tive only to their thickneſs; and when this property is aſcribed to glaſs, to water, &c. it muſt always be underſtood with this reſtriction, that theſe bodies are not too groſs; and that to every ſpecies there is a certain meaſure of thickneſs beyond which the body ceaſes to be tranſparent. There is not one opaque body, on the contrary, which may not itſelf become tranſparent, if reduced to a plate extremely fine. Thus, though gold is not tranſparent, gold leaf is ſo; and on examining the minuter particles of all bodies with a microſcrope, they are found to be tranſparent. It may then be with truth affirmed, that all bodies are tranſparent when reduced to a certain degree of fineneſs; and that no one is ſo when too groſs.

In common language we denominate tranſparent the bodies which preſerve this quality to a certain degree of thickneſs, though they loſe it when they go beyond that bound. But with reſpect to ether, it is of it's own nature perfectly tranſparent, and it's extent diminiſhes not this quality in the ſmalleſt degree. The prodigious diſtance of the fixed ſtars prevents not their rays from being tranſmitted to us. But though our air appears to be of a perfect tranſparency, if it extended as far as the moon, that tranſparency would be entirely loſt, and would prevent every ray of the ſun, and of the other heavenly bodies, from penetrating to us. We ſhould then be involved in Egyptian darkneſs.

The reaſon of it is evident, and we remark the ſame thing in ſound, whoſe reſemblance to light is confirmed

confirmed in every refpect. Air is the moft proper medium for the propagation of found; but the agitations excited in the air are capable of fhaking alfo the particles of all bodies; and thefe again putting in motion the interior particles, finally tranfmit the vibration through the fubftance of all bodies, unlefs they be too thick. There are bodies, then, which, relatively to found, are the fame thing which tranfparent bodies are relatively to light; and all bodies have this property with relation to found, provided they are not too thick. When you are in your apartment, you can hear almoft every thing that paffes in the ante-chamber, though the doors are clofely fhut, becaufe the agitation of the air in the ante-chamber communicates itfelf to the partitions, and penetrates through them into the inner apartment with fome lofs, however. Were the partition removed, you would undoubtedly hear more diftinctly. Now the thicker the walls are, the more of it's force does the found lofe in piercing through them: and the walls may be made fo thick that nothing could be heard from without, unlefs it were fome terrible noife, fuch as a difcharge of cannon.

This leads me forward to a new remark; that very powerful founds may be heard through walls which are impenetrable to founds more feeblc; and, confequently, in order to form a judgment whether a wall is capable of tranfmitting founds, it is neceffary to take into the account not only the thicknefs of the wall, but likewife the ftrengh of the found. If the found is very feeble, a very thin wall is fufficient to ſtop it, though a louder could find an eaſy tranſmiſſion. The ſame thing holds as to bodies which are permeable only to a very ſtrong light. Objects not very brilliant are inviſible through a glaſs blackened with ſmoke, but the rays of the ſun force themſelves through it, and it tranſmits perfectly well the image of that luminary. Aſtronomers employ this method to obſerve him; for without ſuch precaution he would dazzle the eye. And when you happen to be in a dark room, with an aperture in the ſhutter expoſed to the ſun, in vain will you attempt to exclude the light by oppoſing your hand to the aperture; the rays of the ſun will force themſelves through.

It is perceivable at the ſame time that the light of the ſun loſes much of it's luſtre in paſſing through a body which, relatively to other objects, is not itſelf tranſparent. But a very ſtrong light may loſe much of it's luſtre, before it is entirely extinguiſhed, while a feebler light is loſt at once. A piece of very thick glaſs, then, will not be tranſparent, with reſpect to objects leſs brilliant, though the ſun may be viſible through it.

Theſe remarks on tranſparent bodies lead me to the theory of refraction, of which you have frequently heard, and which I ſhall endeavour to place in it's proper light.

18th July, 1760.

LETTER

LETTER XXX.

Of the Tranſmiſſion of Rays of Light, though tranſparent Mediums, and their Refraction.

AS long as light moves in the ſame medium, whether it be ether, air, or any other tranſparent body, the propagation proceeds in ſtraight lines, denominated rays, as they proceed from the luminous point, in all directions, as the radii of a circle, or a globe, iſſue from the centre. In the ſyſtem of emanation, the particles darted from luminous bodies move in ſtraight lines; the ſame thing holds, in that which I have had the honour of propoſing, in which the agitations are communicated in ſtraight lines, as the ſound of a bell is tranſmitted in a ſtraight line, by which alſo we judge from what quarter the ſound comes; the rays in both ſyſtems, then, are repreſented by ſtraight lines, as long as they paſs through the ſame tranſparent medium; but they may undergo ſome inflection, in paſſing from one to another; and this inflection is called the *refraction* of the rays of light, the knowledge of which is neceſſary to account for many phenomena. I proceed, therefore, to lay down the principles, in conformity to which, refraction takes place.*

* The quantity of refraction is not proportional to the denſity of the medium. Sir Iſaac Newton remarks, that inflammable ſubſtances, though ſpecifically lighter than water, produce a much greater refraction: and it was this analogy which ſuggeſted to him, that diamonds belong to the ſame claſs; a conjecture which has been verified within theſe few years.—*E. E.*

It is an invariable law, that, when a ray, ſuch as E C *(plate* I. *fig* 8.) falls perpendicularly on the ſurface A B of another medium, it continues it's progreſs in the ſame ſtraight line extended, as C F; it will, in this caſe, undergo no inflection or refraction. If, then, E C is a ray of the ſun, falling perpendicularly on the ſurface A B of water, or of glaſs, it will enter it in the ſame direction, and continues it's progreſs in the line C F, which is, likewiſe, perpendicular to the ſurface A B, ſo that E F ſhall be in one and the ſame ſtraight line. This is the only caſe in which there is no refraction. But as often as the ray falls not perpendicularly on the ſurface of another tranſparent body, it does not purſue it's progreſs in the ſame ſtraight line; it recedes leſs or more from it, and undergoes a refraction.

Let P C *(plate* I. *fig.* 9.) be a ray, falling obliquely on the ſurface A B, of another tranſparent medium. On entering into this medium, it will not continue it's progreſs in the direction of the ſtraight line C Q, which is the line P C produced; but will recede from it, in the direction of the line C R, or C S. It will undergo, then, at the point C, an inflection, which we call refraction, which depends partly on the difference of the two mediums, and partly on the obliquity of the direction of the ray P C.

In order to comprehend the laws of this *inflection*, it is neceſſary to explain certain terms employed in treating this ſubject.

1ſt. The ſurface A B, which ſeparates the two mediums, that from which the ray comes, and that into which it enters, is called the *refringent furface*. 2dly. The ray P C, which falls upon it, is called the incident ray; and, 3dly, the ray C R, or C S, which purfues, in the other medium, a courfe different from C Q, is called, the *broken*, or *refracted ray*. And, having drawn through the furface A B, the perpendicular line E C F, we call, 4thly, the angle P C E, formed by the incident ray P C, with the perpendicular E C, *the angle of incidence*; and, 5thly, the angle R C F, or S C F, formed by the refracted ray C R or C S, with the perpendicular C F, is called the *angle of refraction*.

Therefore, becaufe of the inflection, which the ray of light undergoes, the angle of refraction is not equal to the angle of incidence P C E; for producing the line P C to Q, the angles P C E and F C Q being vertical, are equal to each other;* as you will eafily recollect. The angle Q C F, then, is equal to the angle of incidence P C E; therefore, the angle of refraction R C F or S C F, is greater or lefs. There are, then, only two cafes which can exift; the one, in which the refracted ray being C R, the angle of refraction R C F, is lefs than the angle of incidence P C E; and the other, in which the refracted ray being C S, the angle of refraction is greater than the angle of incidence P C E. In the former cafe, we fay, that the ray C R approaches the perpendicular C F; and in the other, that the refracted ray C S, recedes or deviates from the perpendicular.

It is neceffary, then, to enquire, In what cafes the

* Euclid's Elements, Book I. Prop. 15.

one

one or the other of theſe changes will take place? And we ſhall find, that this phenomenon depends on the difference of the denſity of the two mediums; or becauſe the rays are tranſmitted with more or leſs difficulty through each of them. To prove this, it muſt be recollected, that ether is of all mediums the moſt rare, and that through which rays are tranſmitted, without the ſlighteſt reſiſtance. After it, the other common tranſparent mediums are thus arranged: air, water, glaſs; thus glaſs is a medium more denſe than water; water than air; and air than ether.

This being laid down, we have only to attend to theſe two general rules: 1ſt. When rays paſs from a medium leſs denſe into one which is more ſo, the refracted ray approaches the more to the perpendicular. This is the caſe, in which the incident ray being P C, the refracted ray is C R. 2dly. When the rays paſs from a medium more denſe to one leſs ſo, the refracted ray recedes from the perpendicular. This is the caſe, in which the incident ray being P C, the refracted ray is C S. Now, this inflection is greater or leſs, according as the two mediums differ in reſpect of denſity. Thus, rays, in paſſing from air into glaſs, undergo a greater refraction, than when they paſs from air into water; in both caſes, however, the refracted rays approach the perpendicular. In like manner, rays paſſing from glaſs into air, undergo a greater refraction than when they paſs from water into air; but in theſe caſes, the refracted ray recedes from the perpendicular.

Finally,

Finally, it muſt likewiſe be remarked, that the difference between the angle of incidence and the angle of refraction is ſo much greater, as the angle of incidence is greater, or, as the incident ray recedes farther from the perpendicular, the greater will be the inflection or refraction of the ray. A relation of all theſe angles exiſts, and is determinable by geometry; but it is not now neceſſary to enter into the detail. What has been already ſaid, is ſufficient for underſtanding what I have farther to propoſe on the ſubject.

22d *July*, 1760.

LETTER XXXI.

Refraction of Rays of different Colours.

YOU have ſeen, that when a ray of light paſſes obliquely from one tranſparent medium to another, it undergoes an inflection, which is called refraction, and that the refraction depends on the obliquity of the incidence, and the denſity of the mediums. I muſt now call upon you to remark, That diverſity of colours occaſions, likewiſe, a ſmall variety in the refraction. This ariſes, undoubtedly, from hence, that the rays which excite in us the ſenſations of different colours, perform unequal numbers of vibrations in the ſame times, and that they differ among themſelves, in the ſame manner as ſharper or flatter ſounds do. Thus, it is obſervable, that

that rays of red undergo the leaſt inflection or refraction; after them come the orange; the yellow, the green, the blue and the violet, follow in order; ſo that violet-coloured rays undergo the greateſt refraction; it being always underſtood, that the obliquity of the incidence, and the denſity of the mediums are the ſame. Hence, it is concluded, that rays of different colours have not the ſame refrangibility; that the red are the leaſt refrangible, and the violet-coloured the moſt ſo.

If then, P C *(plate* I. *fig.* 10.) is a ray paſſing, for example, from air into glaſs; the angle of incidence being P C E, the refracted ray will approach the perpendicular C F; and if the ray be red, the refracted ray will be in the direction C—*red*; if it be orange, the refracted ray will be C—*orange*, and ſo of the reſt, as may be ſeen in the figure. All theſe rays deviate from the line C Q, which is P C produced, toward the perpendicular C F; but the red ray deviates the leaſt from C Q, or undergoes the leaſt inflection, and the violet recedes the fartheſt from C Q, and undergoes the greateſt inflection.

Now, if P C is a ray of the ſun, it produces, at once, all the coloured rays indicated in the figure; and if a piece of white paper is placed to receive them, you will, in effect, ſee all theſe colours; hence, it is affirmed, that every ray of the ſun contains, at once, all the ſimple colours. The ſame thing happens, if P C is a ray of white, or if it proceeds from a white body. We ſee all the colours produced from it by refraction, whence it is concluded, that

that white is an aſſemblage of all the ſimple colours, as we ſhewed formerly. In truth, we have only to collect all theſe coloured rays into a ſingle point, and the colour of white will be the reſult.

It is thus we diſcover what are the ſimple colours. Refraction determines them inconteſtibly. In following the order which it preſents, they are theſe: 1. red, 2. orange, 3. yellow, 4. green, 5. blue, 6. violet. But it muſt not be imagined, that there are but ſix: for as difference of colours ariſes from the number of vibrations which rays perform in one and the ſame time, or rather the undulations which produce them: it is clear, that the intermediate numbers equally give ſimple colours.* But we want names, by which to deſign theſe colours; for be-

* This remark, that the number of primitive colours much exceeds ſix, is very juſt. The colours of the rainbow, or of the ſpectrum, formed by a priſm, paſs into each other by inſenſible ſhades, ſo that it is impoſſible to define their boundaries. There is reaſon to ſuſpect, that, even the great *Newton* was, in this inſtance, miſled, by a predilection for the number ſeven, which during many ages, has been regarded with a ſort of myſtical veneration. The correſpondence, which he obſerved, between the diviſions of the ſpectrum, and thoſe of the monochord, and which ſo many authors have ſince repeated, is wholly ideal; for the proportions, between the extent of the different colours are, in a great meaſure, determined by the peculiar quality of the refracting mediums. Thus a priſm of glaſs, in which alkali predominates, forms a ſpectrum, extremely unlike that formed by one of glaſs, compoſed principally of lead. Were a perſon to reckon only the moſt conſpicuous of the primitive colours, he would, moſt probably, ſelect the number ſix, for the indigo can hardly be diſtinguiſhed.—*E. E.*

tween

tween yellow and green, we evidently perceive intermediate colours, for which we have no ſeparate names.

In conformity to the ſame laws, are produced the colours viſible in the rainbow. The rays of the ſun, in paſſing through the drops of water which float through the air, are, by them, reflected and refracted; and the refraction decompounds them into the ſimple colours. You muſt, undoubtedly, have remarked, that theſe colours follow each other, in the ſame order, in the rainbow, the red, orange, yellow, green, blue, and violet; but we diſcover in it, alſo, all the intermediate colours, as ſhades of one colour to another, and had we more names to diſtinguiſh theſe degrees, we might find more of them from the one extremity to the other. A more copious language may, perhaps, enable another nation actually to reckon up a greater number of different colours; and another, it may be, cannot reckon up ſo many; if, for example, it wants a term to expreſs what we call orange. Some to theſe add purple, which we perceive at the extremity of the red, but which others comprehend under the ſame name with red.

C.	D.	E.	F.	G.	A.	B.
Purple.	Red.	Orange.	Yellow.	Green.	Blue.	Violet.

Theſe colours may be compared to the notes of an octave, as I have done here, becauſe the relations

of

of colours, as well as thoſe of ſounds, may be expreſſed by numbers. There is even an appearance, that by ſtraining the violet a little more, you may come round to a new purple, juſt as in riſing from ſound to ſound, on going beyond B, you come round to *c*, which is the octave above C. And, as in muſic, we give to theſe two notes the ſame name, becauſe of their reſemblance, the ſame thing takes place in colours, which, after having riſen through the intervals of an octave, reſume the ſame names: or, if you will, two colours, like two ſounds, in which the number of vibrations in the one, is preciſely the double of the other, paſs for the ſame, and bear the ſame name.

On this principle it was, that father *Caſtel*, in France, contrived a ſpecies of muſic of colours. He conſtructed a harpſichord, of which every key diſplayed a ſubſtance of a certain colour, and he pretended, that this harpſichord, if ſkilfully touched, would preſent a moſt agreeable ſpectacle to the eye. He gave it the name of the *ocular* harpſichord, and you muſt, undoubtedly, have heard it talked of. For my part, painting rather ſeems to be that to the eye, which muſic is to the ear; and I greatly doubt, whether the repreſentation of ſeveral ſhreds of cloth, of different colours, could be very agreeable.

27th July, 1760.

LETTER

LETTER XXXII.

Of the Azure-colour of the Heavens.

YOU have just seen, that the cause of the visibility of objects, is a motion of vibration extremely rapid, by which the minuter particles of their surfaces are agitated, and that the frequency of these vibrations determines the colour.

It is the same thing, whether these particles be agitated by an intrinsic force, as in luminous bodies, or whether they receive their agitation from illumination, or from foreign rays, by which they are illumined, as in opaque bodies. The frequency or rapidity of the vibrations depends on the grossness of these particles, and on their elasticity, as that of the vibrations of a musical string depends on it's thickness, and degree of tension; thus, as long as the particles of a body preserve the same elasticity, they represent the same colour; as the leaves of a plant preserve a green colour, as long as they are fresh; but when they begin to dry, the difference of elasticity, which then takes place, produces, likewise, a different colour. This subject I have already discussed. I now proceed to explain, Why the heavens appear to us of a blue colour in the day-time.

On observing this phenomenon with a vulgar eye, it would appear, that we are surrounded by a prodigious vault of azure, as painters represent the sky on a ceiling. I have no occasion to undeceive you respecting

respecting this prejudice: a small degree of reflection is sufficient to make you comprehend, that the heavens are not an azure vault to which the stars are affixed, like so many luminous studs. You are perfectly convinced, that the stars are immense bodies, at inconceiveable distances from us, and which move freely through a space almost void, or which is filled only by that subtile matter called ether. And I will shew you, that this phenomenon is to be ascribed to our atmosphere, which is not perfectly transparent.

Were it possible to rise higher and higher above the surface of the earth, the air would become gradually more and more rare; till it ceased to assist respiration; and would, at length, entirely cease; we should then have reached the region of pure ether. Accordingly, in proportion as we ascend on mountains, the mercury in the barometer continues to fall, because the atmosphere becomes lighter and lighter: and then, likewise, it is remarked, that the azure colour of the heavens becomes fainter; and were it possible to mount into pure ether, it would entirely disappear; on looking upward, we should see nothing at all, and the heavens would appear black as night; for where no ray of light can reach us, every thing wears the appearance of black.

There is good reason, then, for asking, Why the heavens appear to be blue? This phenomenon could not exist, were air a perfectly transparent medium, as ether is: in that case, we should receive from above no other rays but those of the stars: but the lustre of day-light is so great, that the feeble light of the ſtars is abſorbed by it. You could not perceive the flame of a taper in the day-time, at any conſiderable diſtance; but that ſame flame, in the night, would appear very brilliant at much greater diſtances. This clearly proves, that we muſt look for the cauſe of the azure-colour of the heavens, in the want of tranſparency in the air. The air is loaded with a great quantity of ſmall particles, which are not perfectly tranſparent, but which, being illuminated by the rays of the ſun, receive from them a motion of vibration, which produces new rays proper to theſe particles; or elſe they are opaque, and become viſible to us from being illumined.

Now, the colour of theſe particles is blue; and this explains the phenomenon: the air contains a great quantity of ſmall blue particles: or it may be ſaid, that it's minuter particles are bluiſh, but of a colour extremely delicate, and which becomes ſenſible to us only in an enormous maſs of air. Thus, in a room, we perceive nothing of this blue; but when the bluiſh rays of the whole atmoſphere penetrate our eyes at once, however delicate the colour of each ſingly, their totality may produce a very deep colour.

This is confirmed by another phenom[illegible], with which you muſt be well acquainted. [illegible] ook at a foreſt, from a moderate diſ[illegible] quite green; but in proportion [illegible] ces, it acquires a bluiſh [illegible] mes deeper and deep[illegible] of Hartz, whi[illegible] ppear [illegible] thence

thence to be blue, but viewed from Halberſtadt, they are green. The great extent of air between Magdeburg and theſe mountains, is the reaſon of it. However delicate or rare the bluiſh particles of the air may be, there is ſuch a prodigious quantity of them in that interval, the rays of which enter into the eye at once, that they repreſent a tolerable deep blue.*

* This explanation of the blueneſs of the ſky is ſtrained and unſatisfactory. The air is, like water, perfectly colourleſs, otherwiſe any portion of it might be diſtinguiſhed by the ſight. Beſides, the blueneſs of the ſky, even in clear weather, is not uniformly the ſame, but acquires different degrees of intenſity, and different ſhades, from a variety of circumſtances, the climate, the ſeaſon, and the elevation of the place. The true explanation of the phenomenon muſt be ſought from other principles. The moſt refrangible rays are, at minute diſtances, attracted or repelled, by colourleſs ſubſtances, with the greateſt force. A ſunbeam, therefore, in it's paſſage through the atmoſphere, will firſt loſe it's violet rays moſt profuſely, next the indigo, then the blue, and if the track be of ſufficient length, perhaps a few of the green. The rays, thus ſeparated, are either abſorbed by the air, or they are reflected, and cauſe the blue appearance. Hence, on the ſummits of lofty mountains, the colour of the heavens ſeems faint and dark, and inclined ſomewhat to violet. On the contrary, in denſe humid air, the colour is a light milky blue. Hence, alſo, the bright azure which paints the ſky of the ſouthern regions, owing to the dryneſs of the air, and the ſhortneſs of the light's tract. For the ſame reaſon, not only the quantity, but even the quality, of the light which we receive from the ſun, depends on the alt[illegible] At riſing, and ſetting, thoſe rays which reach the [illegible] even the lower range of clouds, are chiefly the red[illegible] ter elevation of the ſun, the prevailing colour of [illegible] what orange; and when ſtill higher, it is a dilute [illegible] iples will account for the colour of the ocean,

 which

We remark a ſimilar phenomenon in a fog, when the air is loaded with a great quantity of opaque particles of a whitiſh colour. On looking to only a ſmall diſtance, you ſcarcely perceive the fog; but when the diſtance is conſiderable, the whitiſh colour becomes very perceptible; to ſuch a degree, that it is impoſſible to ſee through it. The water of the ſea appears green at a certain depth; but when you take up a ſmall quantity, as much, for inſtance, as a glaſs will contain, it is ſufficiently diaphonous, and has no ſenſible colour: but in a great extent, when you look toward the bottom, ſo many greeniſh rays collected produce a deep colour.

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which is dark blue. It is only in ſeas, not exceeding one hundred fathoms in depth, that the reflection from the white bottom dilutes the proper colour, and forms a glaucous hue. This appearance is an invariable ſign of the ſhallowneſs of the water, which is often a token of the proximity of the land. Dr. Hally relates an obſervation that he made in a diving-bell, which confirms theſe reaſonings; after deſcending to a great depth in the ſea, he ſtretched out his hand, on which the ſun ſhone through the water, and painted a beautiful crimſon. The ſame obſervation may be extended, even to ſubſtances that are reckoned opaque. Hold an ivory knife in the focus of a burning glaſs, perpendicular to the pencil of light, and a bright yellowiſh ſpot will be perceived on the back. Incline the knife gradually, and the colour of the ſpot will paſs through all the intermediate ſhades, and terminate in a fine red. It is ſcarce neceſſary to remark, that this experiment muſt be performed expeditiouſly, leſt the ivory be ſcorched.—*E.E.*

LETTER

LETTER XXXIII.

Of Rays issuing from a distant luminous Point, and of the visual Angle.

AS long as the rays produced by the rapid vibration of the minuter particles of a body, move in the same transparent medium, they preserve the same direction, or diffuse themselves in all directions, in straight lines. These rays may be represented by the radii of a circle, or rather of a sphere, which, issuing from a centre, proceed in straight lines to the circumference; and it is on account of this resemblance, that we employ the same term *radius*, or ray, to express them, though, properly speaking, the light does not consist of lines, but of very rapid vibrations, going continually forward, in the direction of straight lines: and, for this reason, light may be considered as straight lines, issuing from a luminous point, in all directions.

Let C (*plate* I. *fig.* 11.) be a luminous point, from which rays issue in all directions. Let two spheres be described round C, as a centre, of the one of which, let the great circle be *a b d e*, and of the other A B D E. The light diffused over the surface of the smaller sphere *a b d e*, will likewise occupy that of the greater sphere A B D E. The light, then, must be more faint and weak at the surface of this last, than on that of the smaller sphere *a b d e*. Hence it may be concluded, that the effect of light must be smaller, in proportion to the diſtance from the luminous point. If we ſuppoſe, that the radius of the greater ſphere is double that of the ſmaller, the ſurface of the greater ſphere will be four times as great. Since, therefore, the ſame quantity of light is diffuſed over the ſurface of the greater ſphere, and over that of the ſmaller, it muſt follow, that light, at double the diſtance, is four times more faint; at thrice the diſtance, nine times; at a quadruple diſtance, ſixteen times; and ſo on.*

On applying this rule to the light of the ſun, it will appear, that if the earth were removed to double the diſtance from the ſun, the light derived from him would be rendered four times more faint; and if the ſun were a hundred times farther from us, his brightneſs would be a hundred times a hundred, that is, ten thouſand times leſs. Suppoſing, then, a fixed ſtar to be as great, and as luminous as the ſun, but that it was 400,000 times farther from us, it's light will be 400,000 times 400,000, that is, 160,000,000,000 times more faint than that of the ſun. Hence we ſee, that the light of a fixed ſtar is nothing, compared to that of the ſun; and this is the reaſon that we do not ſee the ſtars in the day time; a feebler light

* As the ſurfaces of ſpheres are to one another as the ſquares of their radii, it muſt be concluded, from what the Author has just now ſaid, that the intenſity of light, at different diſtances from the point which produces it, is in the inverſe ratio of the ſquare of theſe diſtances. It muſt be recollected, that the ſquare of a number is the product which reſults from the multiplication of that number by itſelf.—*F. E.*

always

always difappears in prefence of one much more bright. The fame thing holds good with refpect to candles, and all other luminous bodies, which adminifter lefs light, in proportion to their diftance from us; and you muft have frequently remarked, that however ftrong a light may be, it is infufficient to affift us in reading a printed book, if you remove from it to any confiderable diftance.

There is ftill another circumftance, clofely connected with what I have juft obferved; namely, that the fame object appears fmaller to us, in proportion to it's diftance. A giant, at a great diftance, does not appear taller than a dwarf near us. To form a clearer judgment of this, it is neceffary to attend to the angles at which thefe objects are feen by us.

Let us fuppofe, then, (*plate* I. *fig.* 12,) A B to be an object, fay a man, and that the eye looks at it from the point C. Draw from that point the ftraight lines, A C and B C, which reprefent the extreme rays proceeding from the object to the eye; we call the angle formed at C, the vifual angle of that object for the point C. If we look at the fame object from a fmaller diftance, at D, the vifual angle D will be, undoubtedly, greater: hence it is clear, that the more diftant the fame object is, the fmaller is it's vifual angle; and the nearer it approaches, it's vifual angle becomes greater.

Aftronomers meafure very accurately the angles under which we fee the heavenly bodies, and they have found, that the vifual angle of the fun is fomewhat more than half a degree. If the fun were twice farther from us, this angle would be reduced to the half; and then it will not seem surprizing that it should furnish us four times less light. And if the sun were 400 times farther off, his visual angle would become so many times less, and then that luminary would appear no greater than a star. We must, therefore, carefully distinguish the apparent greatness of any object from it's real greatness. The first is always an angle greater or less, according as the object is nearer or more distant. Thus the apparent greatness of the sun, is an angle of about half a degree, whereas his real magnitude far surpasses that of the earth; for the sun being a globe, his diameter is estimated to be 172,000 German miles,* while the diameter of the earth is only 1720† miles,‡

29th July, 1760.

* 790,000 miles English. † 7,920 miles English.

‡ Astronomers likewise call the apparent diameter of a star the angle under which it is seen. Thus, they say, that the mean diameter of the sun is 31′ 58″; that of the earth, viewed from the sun, would be 17″. Hence it follows, that the diameter of the earth being 2865 leagues, that of the sun is 323,000 leagues. The German mile contains 4000 fathoms, or 24,000 feet. The league of France contains 2282 fathoms. Hence it is easy to reduce the one measurement into the other.—*F. E.*

LETTER

LETTER XXXIV.

Of the Supplement which Judgment lends to Vifion.

WHAT I have now fubmitted to you on the phenomenon of vifion, belongs to optics, which is a branch of mixed mathematics, and which, likewife, holds a confiderable rank in phyfics. Befide colours, the nature of which I have endeavoured to explain, it is the bufinefs of optics to treat of the manner in which vifion acts, and of the different angles under which objects are feen.

You muft have already remarked, that the fame object may be viewed, fometimes under a greater vifual angle, fometimes under a fmaller, as it is lefs or more diftant from us. I fay farther, That a fmall object may be viewed under the fame angle as a great one, when the former is very near, and the latter very diftant. A fmall difh may be placed before the eye in fuch a manner, as to cover the whole body of the fun; and, in effect, a plate of half a foot diameter, at the diftance of 54 feet, exactly covers the fun, and is feen under the fame angle: and yet what a prodigious difference between the fize of a plate and that of the fun: The full moon appears to us under nearly the fame vifual angle as the fun, and, of confequence, nearly as great, though in reality much fmaller; but it is to be confidered, that the fun is almoft 400 times more remote from us than the moon.

The

The vifual angle is a point of fo much the more importance in optics, that the images of the objects, which paint themfelves on the bottom of the eye, depend upon it. The greater or lefs the vifual angle is, the greater or lefs they (the objects) are great or little. And as we fee objects out of ourfelves, only fo far as their images are painted on the bottom of the eye, they conftitute the immediate object of vifion or fenfation. One of thefe images, therefore, leads us to the knowledge only of three things. Firft, it's figure and it's colours conduct to the conclufion, That there is, out of us, a fimilar object, of fuch a figure, and fuch a colour. Secondly, it's magnitude difcovers the vifual angle under which the object appears to us: and, finally, it's place on the bottom of the eye makes us fenfible of the direction of the external object, relatively to us, or that in which the rays emitted from it reach our eyes.

In thefe three particulars confifts the phenomenon of vifion; and we only perceive, 1ft, the figure and colours: 2dly, the vifual angle, or the apparent magnitude; and, 3dly, the direction, or the place in which we conclude that the object exifts. Vifion, then, difcovers to us nothing refpecting either the real magnitude of objects, or their diftances. Though we frequently imagine, that we can determine by the eye the magnitude and diftance of an object, this is not an act of vifion, but of the underftanding. The other fenfes, and habits of long ftanding, enable us to calculate at what diftance an object is from us. But this faculty extends only to objects at no great

diftance.

diſtance. Whenever their diſtance becomes conſiderable, our judgment cannot exerciſe itſelf with certainty; and if ſometimes we venture to hazard a deciſion, it is generally very remote from the truth.

Thus, no one can pretend to ſay that he ſees the magnitude or the diſtance of the moon; and when the vulgar imagine they can judge of the firſt, by conſidering it as equal to that of the terreſtrial bodies which are ſeen under the ſame angle, it is not by viſion they are deceived, but by their judgment, which they want to apply to an object far beyond their reach. It is certain, therefore, that the eyes alone can determine nothing reſpecting the diſtance and magnitude of objects.

To this ſubject may be referred the very remarkable caſe of a man born blind, who obtained ſight, by means of an operation, at an advanced period of life:* This perſon was at firſt dazzled: he could diſtinguiſh nothing as to the magnitude and diſtance of objects. Every thing appeared ſo near, that he wanted to handle them. A conſiderable time, and long practice, were requiſite to bring him to the reel uſe of ſight. He was under the neceſity of ſerving a long apprenticeſhip, ſuch as we perform during the term of childhood, and of which we afterwards preſerve no recollection.

This it is which inſtructed us, that an object appears to us ſo much the more clear and diſtinct as it

* This was the blind man, on whom the famous *Cheſſelden* performed the operation of the couching cataract.—*F. E.*

is

is nearer; and reciprocally, that an object which appears clear and diftinct is near; and when it appears obfcure and indiftinct, that it is at a diftance. It is thus that painters, by weakening the tints of the objects which they wifh to appear remote, and ftrengthening thofe which they would reprefent as nearer, are enabled to determine our judgment, conformably to the effect which they mean to produce. And they fucceed fo perfectly, that we confider fome of the objects reprefented in painting as more diftant than others: an illufion which could not take place, if vifion difcovered to us the real diftance and magnitude of objects.

1ft Auguft, 1760.

LETTER XXXV.

Explanation of certain Phenomena relative to Optics.

YOU have juft feen, that vifion alone difcovers to us nothing, refpecting either the real magnitude or the diftance of objects; and that all we imagine we fee, whether as to the diftance or magnitude of any object, is the effect of judgment. We muft carefully diftinguifh that which the fenfes reprefent to us, from what judgment adds, in which we frequently deceive ourfelves. Many philofophers, who have declaimed againft the accuracy of the fenfes, and who meant thence to infer the uncertainty

tainty of all human knowledge,* have confounded the proper repreſentations of our ſenſes with judgment.

This is their mode of reaſoning: We ſee the ſun no bigger than a trencher, though it be infinitely greater; therefore the ſenſe of ſeeing deceives us; therefore all our ſenſes deceive us; at leaſt, we cannot depend on them: therefore, all the knowledge we acquire by means of the ſenſes, is uncertain, and probably falſe: We, therefore, know nothing. Such is the reaſoning of theſe ſceptics, who boaſt, ſo vain gloriouſly, of their ingenuity; though there be nothing ſo eaſy as to ſay, that every thing is uncertain; and the greateſt dunce may make a ſhining figure in this ſublime philoſophy. But it is abſolutely falſe, that the ſight repreſents to us the ſun no bigger than a pewter plate; it determines nothing whatever reſpecting his magnitude; it is our judgment alone that deceives us. When the objects, however, are not very diſtant we can pronounce with tolerable exactneſs on their dimenſions and diſtances; and the other ſenſes, joined to the degree of clearneſs with which we ſee theſe ſame objects, render our judgments ſufficiently certain. Now, as ſoon as we have the idea of the diſtance of an object, we form to ourſelves, likewiſe, that of it's real magnitude, knowing that it depends on that diſtance.

* Such were the Pyrrhoniſts. We ſtill give the name of *ſcepticiſm*, or Pyrrhoniſm, to this ſtate of univerſal doubt or uncertainty.—*F. E.*

Hence

Hence, the more diſtant we reckon an object to be, the greater we conclude is it's magnitude; and reciprocally, the nearer we conclude it is, the ſmaller we ſuppoſe it. We, of courſe, frequently take one body for another of much greater magnitude, when a ſuſpenſion of judgment prevents our taking diſtance into the account. The reaſon is that a very large body may be ſeen at a great diſtance, under the ſame angle as a ſmall object placed near us.

There is another phenomenon, well known to every one, and which has given occaſion to many diſputes among the learned, and which it is now perfectly eaſy to explain. The full moon appears to every eye at the time of her riſing to be much greater than when ſhe has got to a conſiderable height above the horizon, though the viſual angle of the apparent magnitude be the ſame. The ſun, too, at the time of riſing and ſetting, appears to every one greater than at noon. What then is the foundation of this judgment, ſo univerſal, and ſo falſe? It is undoubtedly becauſe we judge the ſun and the moon in the horizon to be at a greater diſtance from us than when they have got to a conſiderable height.

But how come we to form ſuch a judgment? The common anſwer is, that when the ſun and the moon are in the horizon, we perceive a great many objects between them and us which ſeem to increaſe their diſtance; whereas when the ſun and moon have riſen to a great height, we perceive nothing between them and us, and therefore conclude that they are nearer.

nearer. I know not whether this explanation will be ſatisfactory. It may be objected that an empty apartment appears greater than one completely furniſhed, though the ſize be exactly the ſame; ſeveral intervening objects, therefore, do not always lead us to imagine that one more remote is at a greater diſtance than is really the caſe. I flatter myſelf that the following ſolution will be deemed more natural, and better founded.

Let the circle A (*plate* I. *fig.* 13.) repreſent the earth, and the dotted circle the atmoſphere, or air with which the earth is ſurrounded; ſuppoſe yourſelf ſtationed at the point A, if the moon is in the horizon, the rays will reach you in the direction of the line B A; but in her extreme height, the rays will deſcend in the line C A. In the firſt caſe the rays paſs through the greater ſpace B A; and in the ſecond caſe through the ſmaller ſpace C A. Now, you will pleaſe to recollect, that the rays of light which paſs through a tranſparent medium have their force diminiſhed in proportion to the length of the paſſage. The atmoſphere or air, then, being a tranſparent medium, the ray B A muſt in it's paſſage loſe much more of it's force than the ray C A. Hence it follows, in general, that all the celeſtial bodies appear much leſs brilliant in the horizon than when fully riſen and elevated. We are able to look directly even at the ſun, when he is in the horizon; but when once he has gained a certain height, the eye is conſtrained to ſhrink from his luſtre.

I conclude from this that the moon, too, appears leſs lefs brilliant in the horizon than when elevated.* Now, you will recollect what I said a little above, in fpeaking of effect in painting, that the fame object appears

* This explanation of the appearance of the horizontal moon was offered, in the beginning of the prefent century, by the acute Dr. Berkeley, Bifhop of Cloyne. It has fince been refuted by that excellent optician, Dr. Smith, who was the firft that completely inveftigated this curious fubject. The following is an abftract of the theory, from Dr. Prieftley's "Hiftory of Vifion, Light, and Colours."

"If the furface of the earth were perfectly plane," fays Dr. Smith, "the diftance of the vifible horizon would fcarce exceed 5000 times the height of the eye above the ground, or the diftance of miles (fuppofing the height of the eye to be between five and fix feet) and all objects placed beyond that diftance would appear in the vifible horizon. All objects and clouds, likewife, placed at any diftance beyond this, muft confequently, if they be vifible at all, appear to be in the horizon. "Hence," he fays, "if we fuppofe a vaft wall to be built at the extremity of the plane, beyond the point of vifible diftance, it will not appear ftraight, but circular, as if built upon the circumference of the horizon; and, if continued infinitely, would make a perfect femi-circle. If now this round plane, with the wall upon it, be imagined to be raifed, till it come perpendicular to the reft of the plane, on which a perfon ftands, the wall will appear like the concave figure of the clouds over his head. But though the wall in the horizon appear in the fhape of a femi-circle, yet the cieling will not, but much flatter; becaufe the horizontal plane was a vifible furface, which fuggefted the idea of the fame diftances quite round the eye; but in the vertical plane, extended between the eye and the cieling, there is nothing that affects the fenfe with an idea of it's parts. Confequently the apparent diftances of the higher parts of the cieling will be gradually diminifhed. Now, when the fky is quite overcaft with clouds of equal gravities, they will all float in the air at equal heights above the earth, and confequently will compofe appears to us more diſtant when it's light is weakened: the moon, then, being in the horizon, muſt appear more diſtant than at any point of elevation.

poſe a ſurface reſembling a large cieling, as flat as the viſible ſurface of the earth. It's concavity, therefore, is not real, but apparent; and when the heights of the clouds are unequal, ſince their real ſhapes and magnitudes are all unknown, the eye can ſeldom diſtinguiſh the unequal diſtances of thoſe clouds which appear in the ſame directions, unleſs when they are very near us, or are driven by contrary currents of the air. So that the viſible ſhape of the whole ſurface remains alike in both caſes. And when the ſky is either partly overcaſt, or perfectly free from clouds, it is a fact that we ſtill retain much the ſame idea of it's concavity, as when it was quite overcaſt. But if any one thinks that the reflexion of light from the air is alone ſufficient to ſuggeſt that idea, he would not diſpute it."

"The concavity of the heavens appears to the eye, which is the only judge of an apparent figure, to be a leſs portion of a ſpherical ſurface than an hemiſphere. In other words," he ſays, "the center of the concavity is much below the eye; and, by taking a medium among ſeveral obſervations, he found the apparent diſtance of it's parts, at the horizon, was generally between three and four times greater than the apparent diſtance of it's parts over head."

"This he determined by meaſuring the actual height of ſome of the heavenly bodies, when, to his eye, they ſeemed to be half way between the horizon and the zenith. In this caſe their real altitude was only 23 degrees."

Upon theſe principles Dr. Smith conſtructed the following table:

Sun or Moon's altitude, in degrees.	Apparent Diameters, or diſtances.
00	100
15	68
30	50
45	40
60	34
75	31
90	30

E. E.

The

The confequence is obvious; as we judge the diftance of the moon greater in the horizon, we muft likewife judge her magnitude greater. And in general all the ftars, when near the horizon, appear to us greater, becaufe their apparent diftance is greater.

3d Auguft, 1760.

LETTER XXXVI.

Of Shade.

I HAVE endeavoured to explain almoft all that is ufually treated of in optics. All that remains is to fpeak of fhade. You already know too well what is meant by fhade to render it neceffary for me to dwell long on the fubject. Shade always fuppofes two things: a luminous body, and an opaque body, which does not tranfmit the rays of light. The opaque body, then, prevents the rays of a luminous body from getting behind it, and the fpace which the rays cannot reach, from this interception, is called the fhade of the opaque body, or, what comes to the fame thing, fhade includes all that fpace in which the luminous body is not to be feen, becaufe the opaque body obftructs it's rays.

Let A *(plate* I. *fig.* 14.) be a luminous point, and B C D E an opaque body. Draw the extreme rays A B M, A D N, touching the opaque body. It is evident that no ray of light proceeding from A, can penetrate into the fpace M B E D N; and in what-

ever

ever point within that ſpace the eye may be placed, at O for example, it will not ſee the luminous body. This ſpace is the ſhade of the opaque body, and we ſee that it is continually increaſing, and may extend to infinity. But if the body from which the rays proceed be itſelf of great magnitude, the determination of the ſhade is ſomewhat different. There are three caſes which demand conſideration; the firſt is, when the luminous body is leſs than the opaque; the ſecond, when they are equal; and the third, when the luminous body is the greater. The firſt caſe is that which we have now been conſidering, in which the light is ſmaller than the opaque body.

The ſecond is repreſented, (*plate* I. *fig.* 15.) in which the luminous body A is of the ſame magnitude with the opaque body B C E D. If you draw the extreme rays A B M, A E N, the ſpace M B E N will be ſhaded, and through the whole of that ſpace it will be impoſſible to ſee the luminous body. You ſee, likewiſe, that the lines B M and E N are parallel, and that the ſhade extends to infinity, always preſerving the ſame breadth.

The third caſe is exhibited, (*plate* I. *fig.* 16.) in which the luminous body A A is greater than the opaque body B C E D. The extreme rays, touching the opaque body in B and E, if produced, will meet in the point O, and the ſpace of the ſhade B O E becomes finite, and terminates in O. The ſhade, in this caſe, is termed conical. It is only into this ſpace that the light has no admiſſion, and in which it is

 impoſſible

impoffible to fee the luminous body. To this third cafe belong the fhades of the celeftial bodies, which are much fmaller than the luminous body which enlightens them, namely the fun.

We have here, then, another difplay of the Creator's wifdom. For if the fun were fmaller than the planets, their fhades would not be terminated, but extend to infinity, which would deprive immenfe fpaces of the benefit of the fun's light. But the magnitude of that luminary furpaffing by fo many times that of the planets, their fhades are contracted to very narrow bounds, from which alone the light of the fun is excluded.

It is thus that the earth and the moon project their conical fhades; and the moon may occafionally plunge into the fhade of the earth either partially or totally. When this takes place, we fay the moon is eclipfed, either wholly or in part. In the former cafe we call it a total eclipfe of the moon; in the other, a partial eclipfe. The moon, likewife, projects her fhade, but it is fmaller than that of the earth. It may happen, however, that the fhade of the moon fhould extend as far as to the earth; and then thofe who are involved in that fhade, undergo an eclipfe of the fun. An eclipfe of the fun, then, takes place when the moon, interpofing, prevents our feeing the fun wholly, or in part. We fee not the fun by night, though there be no eclipfe; but we are then in the fhade of the earth, which caufes our greateft obfcurity.

Hitherto

Hitherto we have confidered only the cafes in which the rays of light are tranfmitted in ftraight lines, which is the profeffed object of optics. But it has been already remarked, that the rays of light are fometimes reflected, and fometimes broken, or refracted. You will recollect, that when the rays fall on a well-polifhed furface, fuch as a mirror, they are reflected from that furface; and when they pafs from one tranfparent medium to another, they undergo refraction, and are in fome fenfe broken. Hence arife two other fciences. That which confiders vifion in reference to reflected rays is called catoptrics; and that which has for it's object vifion, in reference to broken or refracted rays, is termed dioptrics. Optics treat of vifion relatively to direct rays of light. I fhall prefent you with a fummary of thefe two fciences, catoptrics and dioptrics, as they difclofe phenomena which are every day prefenting themfelves, and of which it is of importance to inveftigate the caufes and the properties. Every thing relating to the fubject of vifion is, beyond contradiction, an object highly worthy of exciting curiofity, and of engaging attention.

5th Auguft, 1760.

LETTER XXXVII.

Of Catoptrics, and the Reflection of Rays from plain Mirrors.

CATOPTRICS treat of viſion relatively to reflected rays. When rays of light fall on a well poliſhed ſurface, they are reflected in ſuch a manner that the angles on all ſides are equal among themſelves.

To ſet this in a clear light, let A B (*plate* I. *fig.* 17.) be the ſurface of a common mirror, and P a luminous point, whoſe rays P Q, P M, P *m*, fall upon the mirror. Of all theſe rays, let P Q be that which falls perpendicularly on the mirror, and which has this particular and remarkable property, that it is reflected upon itſelf in the direction of Q P; juſt as on a billiard table, when the ball is ſtruck perpendicularly againſt the ledge, it is repelled in the ſelf-ſame direction. But every other ray, as P M, is reflected in the line M N, in ſuch a manner as to make the angle A M N equal to the angle B M P; in which it is to be remarked, that the ray P M is named the incident ray, and M N the reflected ray. In like manner, to the incident ray P *m*, will correſpond the reflected ray *m n*; and, conſequently, becauſe of the reflection, the ray P M is continued in the direction of the line M N, and the ray P *m* in the direction of *m n*, ſo that we have the angle A M N, equal to B M P, and the angle A *m n*, equal to the angle B *m* P

The

Plate I

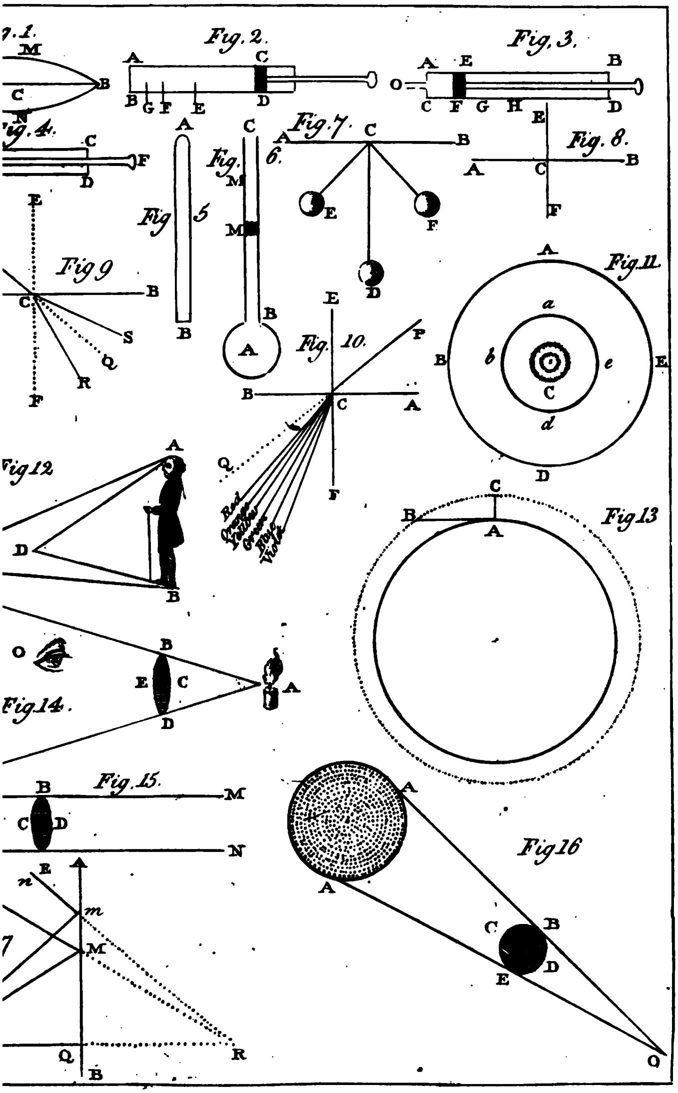

Fig. 2.
Fig. 3.
Fig. 4.
Fig 5
Fig. 6.
Fig. 7.
Fig. 8.
Fig 9
Fig. 10.
Fig 11
Fig 12
Fig 13
Fig 14.
Fig. 15.
Fig 16
Red
Orange
Yellow
Green
Blue
Violet

This property is thus enounced: *The angle of reflection is always equal to the angle of incidence.*

I have already taken notice of this ſtriking property; but my deſign, at preſent, is to ſhew what the phenomemá in viſion are which reſult from it. Firſt, it is evident, that an eye, placed at N, will receive from the luminous point P, the reflected ray M N; thus the ray which excites in that eye the ſenſation of the body from whence it proceeded, comes in the direction M N, juſt as if the object P were in ſome point of that line; hence it follows that the eye muſt ſee the object P in the direction N M.

In order the more clearly to elucidate this fact, we muſt have recourſe to geometry; and you will recollect with pleaſure the propoſitions on which the following reaſoning is founded. Let the perpendicular ray P Q be produced on the other ſide the mirror to R, ſo that Q R ſhall be equal to P Q; I will ſhew you that all the reflected rays, M N, and *m n* being produced behind the mirror, muſt meet in that point. For, taking the two triangles P Q M and R Q M, they have firſt the ſide M Q common to both; then the ſide Q R was made equal to the ſide P Q; and, finally, the angle P Q M being a right angle, it's adjacent angle R Q M muſt likewiſe be a right angle.* Therefore theſe two triangles having each an equal angle contained by two equal ſides, ſhall be every way equal,† and conſequently the angle

* Euclid's Elements, book I. Prop. 13.

† Euclid, book I. Prop. 4.

P M Q equal to the angle R M Q. But the angle A M N, and the angle R M Q, being vertical, are equal to each other,* therefore alſo the angle A M N ſhall be equal to the angle P M Q; that is, the angle of reflection ſhall be equal to the angle of incidence.

In the ſame manner it is demonſtrated that the reflected ray *m n* being produced, would likewiſe paſs through the point R, and conſequently produce in the eye the ſame effect as if the object P were actually placed behind the mirror at R, this point being in the perpendicular P Q R, at the ſame diſtance as P from the ſurface of the mirror, but on different ſides. This will enable you to comprehend clearly why mirrors repreſent objects as if they were behind them; and why we judge that theſe objects are placed as far behind the ſurface of the mirror as they really are before it. It is thus the mirror tranſports objects into another place, without changing their appearance. To diſtinguiſh in the mirror that apparent object from the real, we name the apparent object the image, and we ſay that the images repreſented by reflected rays are behind the mirror. This denomination ſerves to diſtinguiſh real objects from the images of them repreſented in mirrors; and the images which we ſee in mirrors are perfectly equal and ſimilar to the objects, with this exception, that what in the object is on the left appears in the image on the right, and reciprocally. Thus a perſon wearing his ſword on the left ſide, appears with it in the mirror on his right.

* Euclid, book I. Prop. 15.

From

From what has been ſaid, it is always eaſy to ſettle the image of any object whatever behind the mirror.

For A B (*plate* II. *fig.* 1.) being a mirror, and E F an object, ſay an arrow: draw from the points E and F the perpendiculars E G and F H, to the ſurface of the mirror, and produce theſe to *e* and *f*, ſo that E G ſhall be equal to *e* G, and F H to *f* H, *e f* will be the image ſought, which will be equal to the object E F, becauſe the quadrilateral figure G *e f* H is in all reſpects equal to the quadrilateral figure G E F H. It muſt be ſtill farther remarked, that were you even to cut off from the mirror a part, as C B, and A C was the mirror, the image *e f* would not be changed. And conſequently when the mirror is not ſufficiently large to admit the falling of the perpendiculars E G and F H upon it, we muſt ſuppoſe the plane of the mirror to be extended, as we produce lines in geometry when we want to let fall perpendiculars upon them. What I have ſaid reſpects only common mirrors, whoſe ſurface is perfectly plain. Convex and concave mirrors produce different effects.

7th Auguſt, 1760.

LETTER XXXVIII.

Reflection of Rays from convex and concave Mirrors. Burning Mirrors.

EVERY thing relating to the reflection of rays is reduced, as you have ſeen, to two things; the one of which is the place of the image which the reflected rays repreſent; and the other the relation of the

the image to the object. In ordinary or plain mirrors, the image of the object is behind the mirror, at a diſtance equal to that of the object before the mirror, and it is equal and ſimilar to the object. To both of theſe circumſtances we muſt attend when the mirror is not plain; but when it's ſurface is convex or concave; for in either caſe the image is, for the moſt part, ſtrangely disfigured. You muſt frequently have remarked that on preſenting any object before a ſpoon very highly poliſhed, you ſee it's image greatly disfigured, whether reflected from it's interior ſurface, which is concave, or from it's exterior, which is convex.

A globe of ſilver, finely poliſhed, repreſents objects with ſufficient accuracy, but in miniature. If the interior ſurface of the globe is well poliſhed, objects appear upon it magnified; provided always that they are not too diſtant. For the ſame objects may likewiſe appear ſmaller and inverted, if they are removed far from the mirror. There is no occaſion to take a whole globe; any part of it's ſurface whatever produces the ſame effect. Theſe mirrors are denominated ſpherical; and there are two ſorts of them. The one is convex and the other concave, according as they are taken on the exterior or interior ſurface of the ſphere. They are compounded of various metals, ſuſceptible of a fine poliſh; whereas plain mirrors are made of a plate of glaſs, and covered on one ſide with a preparation of mercury, deſigned to ſtop the paſſage of the rays, and to reflect them. I begin with convex mirrors.

Let

Let A C B *(plate* II. *fig.* 2.) be a mirror, the segment of a ſphere, whoſe centre is G. If you place before this mirror an object E, at a great diſtance, it's image will appear behind the mirror, at the point D, the middle point of the radius of the ſphere C G; and the magnitude of this image will be to that of the object, in the relation of the lines C D and C E: it will, therefore, be in this caſe much ſmaller than the object, as the line C D is, in effect, much ſmaller than the line C E. If the object E approaches to the mirror, ſo likewiſe will it's image. This is all demonſtrable on geometrical principles, by ſuppoſing that any incident ray whatever, ſay E M, is reflected in the direction of M N, ſo that the angle B M N may be equal to the angle C M E. Thus, when the eye is at N, receiving the reflected ray M N, it will ſee the object E, according to that direction, and will obſerve it in the mirror, at the point D: or, in other words, D will be the image of the object placed at E, but ſmaller. It is likewiſe eaſy to ſee, that the ſmaller the ſphere is, of which the mirror is a ſegment, the more, likewiſe, is the image diminiſhed.

I proceed to concave mirrors, the uſe of which is very common on many occaſions. Let A C B *(plate* II. *fig.* 3.) be a mirror, forming part of a ſphere, whoſe centre is G, and G C a radius. Let us ſuppoſe an object E, very diſtant from the mirror, it's image will appear before the mirror at D, the middle point of the radius C G: for any ray of light whatever, E M, from the object E, falling on the ſurface of the mirror, at the point M, will be reflected thence,

thence, in ſuch a manner, as to paſs through the point D; and when the eye is placed at N, it will ſee the object at D; but this image will be to the object in the ratio of C D to C E, and conſequently in this caſe ſmaller than it. And when you bring the object nearer to the mirror, the image retires; the object being placed even at the centre G, the image is there likewiſe. If you bring the object ſtill forward to D, the image will retire infinitely beyond E. But if the object be placed ſtill farther forward, between C and D, the image will fall behind the mirror, and appear greater than the object.

When you look at yourſelf in ſuch a mirror, at ſome point between D and C, your face will appear frightfully large. This is explained by the nature of reflection, in virtue of which the angle of incidence, E M A, is always equal to the angle of reflection, C M N. To this ſpecies muſt be referred burning mirrors, and every concave mirror may be employed to burn. This remarkable property merits a more particular explanation.

Let A B C (*plate* II. *fig.* 4.) be a concave mirror, whoſe centre is G, and inſtead of the object, let the ſun be at E; his reflected rays will repreſent the image of the ſun at D, the middle point between C and G. Now, the magnitude of this image will be determined by the extreme rays S C, S C. This image of the ſun will be, accordingly, very ſmall, and as all the rays of the ſun which fall on the mirror A C B are reflected in this image, they will be collected there, and will have ſo much more force, as the

the image D is ſmaller than the ſurface of the mirror. But the rays of the ſun are endowed with the property of heating the bodies on which they fall, as well as that of illuminating them; hence it follows, that there muſt be at D a great degree of heat; and when the mirror is ſufficiently large, this heat may become ſtronger than the moſt ardent fire. In fact, by means of ſuch a mirror, you may burn in an inſtant any combuſtible body, and even melt metals of every kind. It is the image of the ſun alone which produces theſe ſurpriſing effects. This image is uſually denominated the focus of the mirror; it falls always in the middle point of the radius C G; between the mirror and it's centre G.

You muſt carefully diſtinguiſh burning mirrors from burning glaſſes, of which I ſhall give ſome account in my next letter.

9th Auguſt, 1760.

LETTER XXXIX.

Of Dioptrics.

HAVING explained the principal phenomena of catoptrics, which reſult from the reflection of the rays of light; I proceed to treat of dioptrics, whoſe object is to unfold the phenomena of the refraction of rays, which takes place when they paſs through different tranſparent mediums. A ray of light does not purſue the ſame ſtraight line unleſs it continues

continues it's progrefs through the fame medium. As foon as it enters another tranfparent medium, it changes it's direction more or lefs, according as it falls upon it more or lefs obliquely. There is only one cafe in which it purfues a rectilinear courfe, namely, when it enters the other medium perpendicularly.

The inftruments principally to be confidered in dioptrics are the glaffes employed in the conftruction of telefcopes and microfcopes. Thefe glaffes are of a circular form, but with two faces. Every thing relating to them is reducible to the figure of thefe two faces, which may be plain, or convex, or concave. Their convexity, or concavity, is always equal to that of a fphere, of which the radius muft be known, it being confidered as the meafure of the curve of thofe furfaces. This being laid down, we fhall have feveral kinds of dioptric glaffes.

The firft fpecies, No. I. (*plate* II. *fig.* 5.) is that whofe two faces are plain. By cutting a circular piece out of a plate of glafs, of equal thicknefs, we fhall have one of this fpecies, which makes no change on objects either as to magnitude or diftance. Glafs No. II. has one of its furfaces plain, and the other convex; and fuch are termed *plano-convex*. The third fpecies, No. III. has one face plain, and the other concave, and thefe are called *plano-concave*. The fourth, No. IV. has two convex furfaces, and is called *double-convex*. No. V. has two concave furfaces, and called *double-concave*. The fpecies Nos. VI. and VII. have one furface convex and the other concave; and we we give them the name of *meniſcus*. All theſe lenſes are reducible to two claſſes; the one containing thoſe in which convexity prevails, as Nos. II. IV. VI.; in the other, concavity is predominant, namely, Nos. III. V. VII. The former claſs is ſimply denominated convex, and the latter concave. Theſe two claſſes are diſtinguiſhed by the following property.

Let A B (*plate* II. *fig.* 6.) be a convex glaſs, expoſed to a very diſtant object, E F, whoſe rays G A, G C, G B, fall on the glaſs, and, paſſing through it, undergo a refraction, which will take place in ſuch a manner, that the rays proceeding from the point G ſhall meet on the other ſide of the glaſs in the point *g*. The ſame thing will happen to the rays which proceed from every point of the object. By this alteration all the refracted rays A *l*, B *m*, C *n*, will purſue the ſame direction as if the object were at *e*, *g*, *f*, and inverted; and it will appear as many times ſmaller as the diſtance C *g* ſhall be contained in the diſtance C G. We ſay, then, that ſuch a glaſs repreſents the object E F behind it at *e f*, and this repreſentation is called the *image*, which is conſequently inverted, and is, with the object itſelf, in the ratio of the diſtances of the glaſs from the image, and of the glaſs from the object.

It is clear, then, that if the ſun were the object, the image repreſented at *e f* would be that of the ſun; though very ſmall, it will be ſo brilliant, as to dazzle the eye, for all the rays which paſs through the glaſs meet in this image, and there exerciſe their double power of giving light and heat. The heat

there

there is nearly as many times greater, as the ſurface of the glaſs exceeds in magnitude the image of the ſun, named it's focus, from which, if the glaſs be very great, you may produce the greateſt effects of heat. Combuſtible ſubſtances, placed in the focus of ſuch a glaſs, are inſtantly conſumed. Metals are melted, and even vitrified by it; and other effects are produced far beyond the reach of the moſt active and intenſe fire.

The reaſon is the ſame as in the caſe of burning mirrors. In both the rays of the ſun, diffuſed over the whole ſurface of the mirror, or glaſs, are collected in the ſmall ſpace of the ſun's image. The only difference is, that in mirrors the rays are collected by reflection, and in glaſſes by refraction. Such is the effect of convex glaſſes, which are thicker in the middle than at the extremities, and which I have repreſented in Nos. II. IV. and VI. Thoſe repreſented in Nos. III. V. and VII. are thicker at the extremities than at the middle, and being all comprehended under the term concave, produce a contrary effect.

Let A C B *(plate* II. *fig.* 7.) be a glaſs of this form. If you expoſe to it, at a great diſtance, the object E G F, the rays G A, G C, G B, proceeding from the point G, will undergo a refraction, on leaving the glaſs, in the direction of A *l*, C *m*, and B *n*, as if they had iſſued from the point *g*; and an eye placed behind the glaſs, at *m*, for example, will ſee the object juſt as if it were placed at *e g f*, and in a ſituation ſimilar to that in which it is at the point G, but as many times ſmaller as the diſtance C G exceeds the diſtance

diſtance G g. Convex glaſſes, then, repreſent the image of a very diſtant object behind them; concave glaſſes repreſent it before them; the former repreſent it inverted, and the latter in it's real ſituation. In both, the image is as many times ſmaller as the diſtance of the object from the glaſs exceeds that of the glaſs from the image. On this property of glaſſes is founded the conſtruction of teleſcopes, ſpectacles, and microſcopes.

11th Auguſt, 1760.

LETTER XL.

Continuation. Of burning Glaſſes and their Focus.

CONVEX glaſſes furniſh ſome farther remarks, which I beg leave to ſay before you. I ſpeak here of thoſe glaſſes in general which are thicker in the middle than at the extremities; whether both ſurfaces be convex, or one plane and the other convex; or, finally, one concave and the other convex, provided, however, that the convexity exceed the concavity, or that the thickneſs be greater at the middle than at the extremities. It is farther ſuppoſed that the glaſſes have a ſpherical figure.

They have firſt this property, that being expoſed to the ſun, they preſent behind them a focus, which is the image of that luminary, and which is endowed, like it, with the property of illuminating and burning. The reaſon is that all the rays iſſuing from the ſun, and falling on this ſurface, are collected by the refraction of the glaſs into a ſingle point. The ſame thing happens whatever be the object expoſed to ſuch a glaſs; it always preſents the image of it, which you ſee inſtead of the object itſelf. The following figure will render what I have ſaid more intelligible.

Let A B C D (*plate* II. *fig.* 8.) be a convex glaſs, before which is placed an object E G F, of which it will be ſufficient to conſider the three points E, G, F. The rays which, from the point E, fall upon the glaſs, are contained in the ſpace A E B; and are all collected in the ſpace A *e* B by refraction, ſo as to meet in the point *e*. In the ſame manner the rays from the point G, which fall on the glaſs, and which fill the ſpace A G B, are comprehended, by means of refraction, in the ſpace A *g* B, and meet in the point *g*. Finally, the rays from the point F, which fall on the glaſs in the angle A F B, are refracted ſo as to meet in the point *f*. Thus we ſhall have the image *e g f* in an inverted poſition behind the glaſs; and an eye placed at O, behind the image, will be affected in the ſame manner as if the object were at *e g f*, inverted, and as many times ſmaller as the diſtance D *g* is ſmaller than the diſtance C G.

In order to determine the place of the image *e g f*, we muſt attend as well to the form of the glaſs as to the diſtance of the object. As to the firſt, it may be remarked, that the more convex the glaſs is, in other words, the more that the thickneſs of the middle C D exceeds that of the extremities, the nearer the

image

image will be to it's furface. With regard to the diftance, if you bring the object E F nearer to the glafs, it's image *e f* retires from it, and reciprocally. The image cannot be nearer to the glafs than when the object is at a very great diftance from it; it is then at the fame diftance as that of the fun would be, which is denominated the focus of the lens. When the object, then, is very diftant, the image falls in the very focus, and the nearer you bring the object to the glafs the farther the image retires from it, and that in conformity to a law in dioptrics, by means of which you can always determine the place of the image, for every diftance of the object, provided you know the focus of the glafs, that is, the diftance at which it collects the rays of the fun, in a fpace fufficiently fmall to fet on fire a body expofed to it.

The point where the rays meet is, as has been faid, the place of the image. Now, this point is eafily found by experience. The different denominations of glaffes are derived from it, as when we fay, fuch a glafs has it's focus at the diftance of an inch, another at the diftance of a foot, another at the diftance of ten feet, and fo on; or, more concifely, a glafs of an inch, a foot, or ten feet focus. Long telefcopes require glaffes of a very diftant focus, and it is extremely difficult to make them exact. I once paid 150 crowns for one lens, which I fent to the academy of Peterfburg; it has it's focus at the diftance of 600 feet: I am convinced it was of no great value; but they would have it on account of it's rarity.

To be satisfied that the representation of the image *c g f*, in the preceding figure, is real, you have only to hold at that place a piece of white paper, the particles of which are susceptible of the different kinds of vibrations on which colours depend. Then all the rays from the point E of the object, on meeting at the point *e*, will put the particles of the paper into a movement of vibration similar to that which the point E has, and consequently you will see the point *e* of the same colour as the point E. In like manner the points *g* and *f* will have the same colours as the points G and F of the object; and you will likewise see on the paper all the points of the object expressed in their natural colours; which will represent the most exact and the most beautiful picture of the object. This will succeed perfectly well in a dark room by applying a convex lens to a hole made in the shutter. You will then see on a sheet of white paper, placed opposite to the aperture in the shutter, all the external objects so exactly painted, that you may trace them with a pencil. Painters make use of such a machine for designing landscapes and other views.*

13th August, 1760.

* The hypothesis of light, contained in the preceding letters, was first proposed in the middle of last century by the ingenious Mr. Huggens; but after the brilliant discoveries of Sir Isaac Newton, it fell into oblivion, where it ought ever to have remained. What induced Mr. Euler to revive it, it is difficult to conceive. This hypothesis is not likely to have many abettors in the present age. As it appeals wholly to the imagination, it requires not any formal refutation. I shall mention a single objection, which seems to be conclusive: If ether were the vehicle of light, as air and water are of sound, the ear would likewise be, in some degree, an organ of vision.

LETTER XLI.

Of Vision, and the Structure of the Eye.

I AM now enabled to explain the phenomena of vision, which is undoubtedly one of the greatest operations of nature that the human mind can contemplate. Though we are very far short of a perfect knowledge of the subject, the little we do know of it is more than sufficient to convince us of the power and wisdom of the Creator. We discover in the structure of the eye perfections which the most exalted genius could never have imagined.

I shall not detain you at present with an anatomical description of the eye. It is sufficient to remark, that the exterior membrane *a* A *b* (*plate* II. *fig.* 9.) is transparent, and is called the *cornea* of the eye; behind this, on the inside, is another membrane *a m*, *b m*, circular and coloured, which we call the *iris*, in the middle of which is an aperture *m m*, called the *pupil*, which appears to us to be black. We find behind this aperture, the *crystalline* humour *b* B C *a*, which is a body somewhat like in form to a small burning glass; it it perfectly transparent, and of a membranous substance. Behind the crystalline humour the cavity of the eye is filled with a transparent jelly, called the *vitreous humour*. The anterior space between the horny tunicle *a* A *b*, and the cryscan enter into the eye, to form on the retina the image which appears painted there; thus, the more the pupil is opened, the more brilliant this image will be.

On carefully examining the human eye, we obſerve, that the aperture of the pupil is ſometimes greater and ſometimes ſmaller. It is generally remarked, that the pupil is contracted when expoſed to a very ſtrong light; and, on the contrary, very much dilated where the light is faint. This variation is abſolutely neceſſary to the perfection of viſion. When we are in a very ſtrong light, the rays being more powerful, fewer of them are wanted to agitate the nerves of the retina; the pupil, accordingly, is then more contracted. Were it more dilated, and conſequently admitted more rays, their force would agitate the nerves too violently, and occaſion pain. It is for this reaſon we are unable to look upon the ſun without being dazzled, and without ſenſible pain in the bottom of the eye.

Were it poſſible for us to contract the pupil ſtill more, ſo as to admit only a very ſmall quantity of rays, we ſhould not be very greatly incommoded by it; but the contraction of the pupil is not in our own power. Eagles poſſeſs this advantage, and are able to look directly at the ſun; it is accordingly remarked, that their pupil is then ſo much contracted, as to appear reduced to a point. A clear light, requiring a very ſmall dilatation of the pupil, in proportion as the light decreaſes, the pupil dilates, and in the dark is ſo enlarged, as almoſt to occupy the whole

whole of the iris. If it remained in the ſame ſtate of contraction as in the light, the rays which enter into it would be too weak to agitate the nerves as much as is neceſſary to perception; the rays muſt, therefore, be then admitted in greater abundance, in order to produce a ſenſible effect.

Were it in our power to open the pupil ſtill more, we ſhould be able to ſee in a greater degree of darkneſs. To this purpoſe we are told of a perſon, who, having received a blow on his eye, the pupil was ſo dilated by it, that he could read, and diſtinguiſh the minuteſt objects in the dark. Cats and ſeveral other animals which roam in the dark, have the faculty of enlarging the pupil much more than the human ſpecies; and owls have theirs at all times too much dilated to bear even a moderate degree of light.

Now, when the pupil of the human eye dilates or contracts, it is not by an act of the will; man not having the power of dilating or contracting the pupil at pleaſure. As ſoon as he enters into a luminous ſituation, it ſpontaneouſly contracts and dilates on his return to darkneſs. But this change is not produced in an inſtant; it requires a little time for this organ to accommodate itſelf to circumſtances.

You muſt, no doubt, have remarked, that as often as you make a very ſudden tranſition from a clear light to a dark place, as in the theatre of *Schuck*, you could not at firſt diſtinguiſh the company. The pupil was ſtill too narrow to permit the few feeble rays which it admitted to make a ſenſible impreſſion; but it gradually dilated to receive a ſufficiency of rays.

The

The contrary happens, when you paſs ſuddenly from darkneſs to a clear light. The pupil being then very much expanded, the retina is ſtruck in a lively manner, you are quite dazzled, and under the neceſſity of ſhutting your eyes.

It is then a very remarkable circumſtance that the pupil ſhould dilate and contract according as viſion requires, and that this change ſhould take place almoſt ſpontaneouſly and independently of any act of the will. Philoſophers who examine the ſtructure and the functions of the human body, are greatly divided in opinion as to this ſubject, and there is little appearance that we ſhall ever have a ſatisfying ſolution of this wonderful phenomenon. The variability of the pupil is, however, an object eſſentially neceſſary to viſion; and without which it would be very imperfect. But various other particulars are diſcoverable, equally entitled to admiration.

17th Auguſt, 1760.

LETTER XLIII.

Farther Continuation. Aſtoniſhing Difference between the Eye of an Animal, and the artifical Eye, or camera obſcura.

THE principle on which the ſtructure of the eye is founded, is, in general, the ſame as that according to which I explained the repreſentation of objects on white paper by means of a convex lens. Both

Both of them muſt be reſolved into this, that all the rays, proceeding from one point of the object, are again collected in a ſingle point by refraction; and it ſeems of little importance whether this refraction is performed by a ſingle lens, or by the ſeveral tranſparent ſubſtances of which the eye is compoſed. It might even be inferred from thence, that a ſtructure more ſimple than that of the eye, by employing one ſingle tranſparent ſubſtance, would have been productive of the ſame advantages; which would amount to a very powerful objection againſt the wiſdom of the Creator, who has aſſuredly purſued the ſimpleſt road in the formation of all his works.

Perſons have not been wanting who, from not having attentively examined the advantages reſulting from the apparent complication, preſumed to cenſure this beautiful production of the Supreme Being with a levity worthy of cenſure. They have pretended it was in their power to produce a plan more ſimple for the ſtructure of the eye, becauſe they were ignorant of all the functions which that organ had to diſcharge. I ſhall examine this plan of theirs; and I hope to convince you, that it would be highly defective, and altogether unworthy of being put in competition with that which actually exiſts.

Such an eye, therefore, would be reduced to a ſimple convex lens, A B C D, (*plate* II. *fig.* 10.) which collects, in a point, all the rays coming from one and the ſame correſponding point in the object. But this is only near to the truth. The ſpherical form, given to the ſurfaces of a lens, is liable to this inconvenience, ther, they undergo a different refraction; that rays of a red colour undergo the leaſt refraction, and violet-coloured rays the greateſt. Hence, if the point O were red, and if it's rays, in paſſing through the lens A B, were collected at the point R, this would be the place of the red image. But if the point O were violet, the rays would be collected nearer to the lens, at V. Again, as white is an aſſemblage of all the ſimple colours, a white object, placed at O, would form ſeveral images at once, ſituated at different diſtances from the point O; the reſult of which would be, on the retina, a coloured ſpot that would greatly diſturb the repreſentation.

It is accordingly obſervable, that when in a dark room the external objects are repreſented on white paper, they appear bordered with the colours of the rainbow, and it is impoſſible to remedy this defect by employing only one tranſparent body. But it has been remarked, that this may be done by means of different tranſparent ſubſtances; but neither theory nor practice have hitherto been carried to the degree of perfection neceſſary to the execution of a ſtructure which ſhould remedy all theſe defects.* The human

* A ſimilar defect has been remarked in the common teleſcope. Objects do not appear in it very clearly. You ſee, beſides, at the circumference of the field which it encompaſſes, a mixture of colours, which is called *iris*. To remedy this inconveniency, achromatic teleſcopes have been conſtructed, whoſe object-glaſs, being compoſed of more than one lens of different denſities, and which of conſequence refract the rays differently, produce an effect analogous to that of the tranſparent ſubſtances of the eye, of which our Author has been treating.—*F. E.*

eye,

eye, however, labours under none of the imperfections which I have mentioned, nor many others to which the hypothetical eye we have been analyzing would be liable. What a ſublime idea muſt we form of Him who has furniſhed not only the whole human ſpecies, but every animal, nay even the vileſt inſects, with an organ of ſuch curious conſtruction!*

* The object of the Tranſlator being not only to diſplay *Euler's* philoſophy, but likewiſe to exhibit the man as deſigned by his own pencil, he takes the liberty of preſenting the Engliſh Reader with the concluſion of this letter, in the Author's own manner and words, tranſcribed from the original edition of this work. Though a French philoſopher and ſtateſman may feel aſhamed of the alliance of ſcience to religion, and endeavour to keep it out of ſight, it would ſurely ill become us to follow the example. Let the Author expreſs his own ſentiments in his own way.

"But the eye which the Creator has formed is ſubject to no "one of all the imperfections under which the imaginary con"ſtruction of the freethinker labours. In this we diſcover the "true reaſon why infinite wiſdom has employed ſeveral tranſpa"rent ſubſtances in the formation of the eye: it is thereby ſe"cured againſt all the defects which characteriſe every work of "man. What a noble ſubject of contemplation! How pertinent "that queſtion of the Pſalmiſt! *He who formed the eye, ſhall he not* "*ſee? and He who planted the ear, ſhall He not hear?* The eye alone "being a maſter-piece that far tranſcends the human underſtand"ing, what an exalted idea muſt we form of Him, who has be"ſtowed this wonderful gift, and that in the higheſt perfection, "not on man only, but on the brute creation, nay, on the vileſt "of inſects!"—*E. E.*

19th Auguſt, 1760.

LETTER

LETTER XLIV.

Perfections discoverable in the Structure of the Eye.

THE eye, then, infinitely surpasses every piece of mechanism which human skill is capable of producing. The different transparent substances of which it is composed, have not only a degree of density capable of causing different refractions, but their figure is likewise determined in such a manner that all the rays proceeding from one point of the object are exactly collected in one and the same point, whether that object be more or less distant, whether it be situated directly or obliquely with respect to the eye, and though it's rays undergo different refractions.

Were the least change to be made in the nature and figure of these substances, the eye would lose all the advantages which we have been admiring. The strength of our sight is exactly proportioned to the extent of our necessities; and far from complaining that objects too remote escape this organ, we ought, on the contrary, to consider it as one of the most precious gifts of the Supreme Being.*

It

* Mr. *Euler's* idea is ingenious, that the three pellucid substances of which the eye is composed serve to correct the unequal refrangibility of the rays of light, and produce a perfect picture on the retina. Unfortunately this perfection is merely ideal, nor is the eye an achromatic instrument. A very simple experiment will evince the truth of this remark. Make two parallel black strokes adjacent to each other, on a bit of paper; shut the one eye, and

hold

It muſt be farther remarked, that in order to ſee objects diſtinctly, it is not ſufficient that the rays which come from one point ſhould be collected in another. It is likewiſe neceſſary, that the point of re-union ſhould fall preciſely on the retina; if it fell either ſhort of, or beyond it, viſion would become confuſed. Now, if for a certain diſtance of objects, this point of union fall upon the retina, thoſe of more diſtant objects would fall in the eye ſhort of the retina; and thoſe of nearer objects would fall beyond the eye. In either caſe there would be a confuſion in the image painted on the retina.

The eyes of every man, therefore, are conſtructed for a certain diſtance. Some perſons ſee diſtinctly only ſuch objects as are very near to their eyes; we call them *Myops*, that is, ſhort-ſighted. Others, on the contrary, named *Preſbytes*, ſee diſtinctly objects only which are very diſtant. And thoſe who ſee diſtinctly objects at a moderate diſtance, are ſaid to have good eyes. Both the other two, however, have the power of contracting or dilating the globe of the eye to a certain degree, and thereby of bringing

hold the paper about half a foot from the other, in a ſtrong light, and bring it gradually nearer; at a certain diſtance the ſtrokes will appear fringed with rainbow-colours. The Roman characters III or IIII, on the dial-plate of a watch, will anſwer ſtill better. But though the eye is not conſtructed with mathematical accuracy, that organ is adapted, with ſufficient nicety, for all the ordinary purpoſes of life. They miſtake extremely the views of nature, who look for perfection in her works: ſhe is, in general, ſparing in her favours, and reſerves exquiſite ſkill for extraordinary occaſions.—*E. E.*

nearer

nearer, or of removing, the retina, which enables them, likewiſe, to ſee clearly, objects a little more or leſs diſtant; this, undoubtedly, greatly contributes to render the eye more perfect, and it cannot ſurely be aſcribed to chance merely.

Thoſe who have good eyes, derive moſt advantage from their ſtructure, as they are thus in a condition to ſee diſtinctly, objects very diſtant, and very near; but this never exceeds a certain bound. There is, perhaps, no one who can ſee at the diſtance of an inch, and, conſequently, ſtill leſs at a ſmaller diſtance. If you hold a writing cloſe to your eyes, you will ſee the characters but very confuſedly. This is all I preſume to offer, on a ſubject of ſuch high importance.

21ſt Aug. 1760.

LETTER XLV.

Of Gravity, conſidered as a general Property of Body.

HAVING now treated of light, I proceed to the conſideration of a property common to all bodies, that of gravity. We find that all bodies, ſolid and fluid, fall downward, when they are not ſupported. I hold a ſtone in my hand; if I let it go, it falls to the ground, and would fall ſtill farther, were there an aperture in the earth. While I write, my paper would fall to the ground, were it not ſupported by the table. The ſame law applies to every body with which we are acquainted. There is not one that would not fall to the ground, if it were not ſupported, or ſtopped by the way.

The cauſe of this phenomenon, or of this propenſity of all bodies, is denominated gravity. When it is ſaid, that bodies are heavy, or poſſeſs gravity, we mean, that they have a propenſity to fall downward, and actually would fall, if we remove what before ſupported them.

The ancients were little acquainted with this property. They believed that there were bodies which had, naturally, a tendency to riſe, ſuch as ſmoke and vapours; and ſuch bodies they termed light, to diſtinguiſh them from thoſe which have a tendency to fall. But it has been diſcovered, by experiment, that it is the air which raiſes theſe ſubſtances aloft; for in a ſpace void of air, it is well known, by means of the air-pump, that ſmoke and vapours deſcend as well as ſtone, and that theſe ſubſtances are, of their own nature, heavy, like others. When, therefore, they riſe into the air, the ſame law acts upon them which acts upon a log of wood plunged into the water. Notwithſtanding it's gravity, it ſprings up, as ſoon as you leave it to itſelf, and ſwims, becauſe it is not ſo heavy as water; and, in virtue of a general rule, all bodies riſe in a fluid of more gravity than themſelves.

If you throw a piece of iron, of copper, of ſilver, and even of lead, into a veſſel full of quickſilver, they ſwim on the ſurface, and if you force them down, they re-aſcend when left to themſelves. Gold

alone

alone finks, becaufe it is heavier than quickfilver. And, fince there are bodies which rife in water, and in other fluids, notwithftanding their gravity, for this reafon merely, that they are not fo heavy as water, or thofe other fluids; it is not at all furprizing, that certain bodies, lefs weighty than air, fuch as fmoke and vapours, fhould rife in it.

I have already remarked, that air itfelf poffeffes gravity, and that by means of this gravity, it fupports the mercury in the barometer. When, therefore, it is affirmed, that all bodies are heavy, it is to be underftood, that all bodies, without a fingle exception, would fall downward in a vacuum. I might venture to add, that they would fall with an equal degree of rapidity; for a feather and a piece of gold defcend with equal velocity in an exhaufted receiver.

It might be objected to this general property of body, that a fhell, difcharged from a mortar, does not at once fall to the ground, like a ftone, which I let drop from my hand, but mounts into the air. It cannot, however, be inferred, that the fhell has no gravity; for it is evident, that the ftrength of the powder hurls the bomb aloft, and but for this, it would, without doubt, immediately fall to the ground. And we fee, in fact, that it does not continue always to afcend, but as foon as the force, which carries it upward, is exhaufted, down it comes with a rapidity, that crufhes every thing it meets, a fufficient proof of it's gravity.

When, therefore, it is affirmed, that all bodies are heavy, no one means to deny that they may be ſtopped, or that they may be thrown aloft; but this is effected by an external power, and it remains indubitably certain, that all bodies whatever, as ſoon as left to themſelves, at reſt, or without motion, will aſſuredly fall when no longer ſupported. There is a cellar under my apartment, but the floor ſupports me, and preſerves me from falling into it. Were the floor ſuddenly to crumble away, and the arch of the cellar to tumble in at the ſame time, I muſt infallibly be precipitated into it, becauſe my body is heavy, like all other bodies with which we are acquainted. I ſay, *with which we are acquainted*, for there may, perhaps, be bodies deſtitute of weight; ſuch as, poſſibly, light itſelf, the elementary fire, the electric fluid, or that of the magnet.*

Except theſe bodies, the gravity of which is not

* I muſt once more take the pious *Euler* out of the hands of the *quondam* Marquis, and let him ſpeak for himſelf. The inſtance which the Author adduces, of bodies that, poſſibly, are deſtitute of gravity, is one taken from divine Revelation, that of the angels. "Such," ſays he, "as the bodies of angels, which have "formerly appeared to men. A body, like this, would not fall "downward, though the floor were ſuddenly to be removed from "under it, but would move as firmly through the air, as on the "
It is amuſing to obſerve, with what ſolicitude the Pa-
notator keeps clear of every thing that ſavours of religion.
henſive, that a ſingle drop of water from Scripture,
te the whole maſs of philoſophy. His terror is,
tion, that of Macbeth.

t Neptune's ocean waſh this blood
my hand? No; this my hand will rather
dinous ſeas incarnadine,
d green one red. SHAKESPEAR.

yet

yet confirmed by experiment, gravity may be conſidered as a general property of all the bodies which we know, in virtue of which, they all have a tendency to fall downward, and actually do ſo, when nothing oppoſes their deſcent.

23d Aug. 1760.

LETTER XLVI.

Continuation. Of ſpecific Gravity.

YOU have juſt ſeen, that gravity is a general property of all the bodies with which we are acquainted, and that it conſiſts in the effect of an invincible force, which preſſes them downward.

Philoſophers have warmly diſputed, whether there actually exiſts a power, which acts in an inviſible manner upon bodies; or whether it be an internal quality, inherent in the very nature of the bodies, and, like a natural inſtinct, conſtraining them to deſcend. The queſtion amounts to this: If the cauſe of gravity is to be found in the very nature of every body; or if it exiſts without it, ſo that were this extrinſic power to fail in it's operation, the body would ceaſe to be heavy? Before we attempt a ſolution of this, it will be neceſſary to examine, more carefully, all the circumſtances connected with gravity.

I remark, firſt, that when you ſupport a body to prevent it's falling, if it reſts on a table, it's preſſure is equal to the force with which it would tend to fall; and if a thread is affixed to it, by which it may be suspended, the thread is stretched by that force; in other words, by the gravity of that body; so that if the thread were not of a certain strength, it would break. We see, then, that all bodies exercise a degree of force on the obstacles which support them, and prevent their falling, and that this action is precisely the same as that which would make the body descend, if it were at liberty. When a stone is laid upon a table, the table is pressed by it. You have but to put your hand between the stone and the table, to be sensible of this force, which may be increased to such a degree as even to crush the hand. This force is called the gravity of the body; and it is clear, that the weight, or the gravity, of every body, signifies the same thing, both denoting the force with which that body is pressed downward, whether this force exists in the body itself, or out of it.

We have an idea too clear of the weight of bodies, to make it necessary to dwell longer on the subject. I only remark, that when two bodies are joined together, their weight too is added, so that the weight of the compound is equal to the sum of the weight of the parts. From this we see, that the weight of bodies may be very different. We have also the certain means of exactly measuring and comparing them, by the help of a balance, which has the property of resting in equilibrium, when the bodies, put in it's two scales, are of equal gravity. In order to make this comparifon, we agree on fome fixed meafurement, of a certain determinate weight, fuch as a pound, and, by means of a good balance, all bodies may be weighed, and their gravity afcertained, according to the number of pounds which they contain. A body too great to be put into the fcale of a balance may be divided, and the parts being weighed feparately, you have only to add the particulars. The weight of a whole houfe, however large, may be thus afcertained.

You muft, no doubt, have frequently remarked, that a fmall piece of gold weighs as much as a piece of wood greatly fuperior in fize; a proof that the gravity of bodies is not always regulated by their magnitude; a very fmall body may be of great weight, while a very large one may be light. Every body, then, is fufceptible of two meafurements, entirely different from each other. The one determines it's magnitude or extent, called likewife it's fize; this meafurement belongs to the province of geometry, which teaches the method of meafuring the magnitude or extent of bodies. The other mode of meafurement, by which their weight is determined, is totally different, and ferves to diftinguifh the nature of the different fubftances of which bodies are formed.

You can eafily conceive feveral maffes of different fubftances, all of the fame magnitude, or extent; each, for example, of a cubic figure, whofe length, breadth, and height, fhall be a foot. Such a mafs, if it be of gold, would weigh 1330 pounds; if of silver, 770 pounds; if of iron, 500 pounds; and if of water, only 70 pounds; were it of air, it would weigh no more than the twelfth part of a pound. From this you see, that the different substances of which bodies are composed, vary considerably in respect of gravity.

To express this difference, we employ certain terms, which might appear equivocal, if they were not perfectly understood. Thus, when it is said, that gold is heavier than silver, it is not to be understood, that a pound of gold is heavier than a pound of silver; for a pound, of whatever substance, is always a pound, and has always precisely the same weight; but the meaning is, that having two masses of the same size, the one gold and the other silver, the weight of the mass of gold will exceed that of the silver. And when it is said, that gold is 19 times heavier than water, we mean, that having two equal masses, the one of gold, the other of water, that which is of gold will have 19 times the weight of that which is of water. When we thus express ourselves, we say nothing of the absolute weight of bodies, we only speak by way of comparison, and with a reference always to masses of an equal size. Neither is it of importance, whether the size be great or small, provided they be equal.

25th Aug. 1760.

LETTER

LETTER XLVII.

Terms relative to Gravity, and their true Import.

GRAVITY, or weight, ſeems ſo eſſential to the nature of bodies, that it is almoſt impoſſible to form the idea of a body diveſted of this quality. And it's influence is ſo univerſal, in all our operations upon body, that we muſt, in every inſtance, pay attention to it's gravity, or weight. As to our own perſons, whether we ſtand, ſit, or lie, we continually feel the effect of the gravity of our own body: we could never fall, if the body were not, as well as all it's parts, endowed with this force. Language itſelf is regulated according to this property of bodies. The place toward which a body tends in it's deſcent, we term *low*; and the oppoſite direction from the body, we term *high*.

It muſt be remarked, that when a body, in falling, is at perfect liberty, it always deſcends in a ſtraight line, purſuing which, it's direction is ſaid to be downward. This line is likewiſe called *vertical*, by which term we always mean a ſtraight line, drawn from high to low; and if we conceive this line produced upward, till it reaches heaven, we call that point in the heavens our *zenith*, an Arabian word, denoting that point in the heavens which is directly over our head. You comprehend, then, that a vertical line, is that ſtraight line in which a body falls, when no longer ſupported. When you affix a thread

to

words at the place where we are. For navigators who have made the circuit of the globe, observe, that their head and feet had throughout maintained the same position relatively to the surface of the terrestrial globe.

Some persons whom this phenomenon embarrassed, formerly thought of explaining it, by the comparison of a globe, over the surface of which you see flies and other insects crawl on the under as well as the upper part. But they did not consider that the insects on the dependent surface adhere to it by their claws, and, without this assistance, would presently fall off. The antipode, then, must have his shoes furnished with hooks to hold him fast to the surface of the earth: but though he has none, he falls not any more than we do. Besides, as we imagine ourselves to be on the uppermost surface of the earth, the antipode has the same idea of his situation, and considers us as undermost.

But the whole phenomena are easily accounted for, on the hypothesis which experience has demonstrated, that the direction of gravity is sensibly perpendicular to the surface of the earth, at every point of that surface; that it varies at these different points; and that at those which are antipodes to each other, it must be exactly opposite. The terms *upward* and *downward*, therefore, do not express an invariable direction, but the direction of gravity, wherever it is. Our antipodes have their heads *downward* only with relation to us, but not with relation to themselves; they, as well as we, are in the position which the

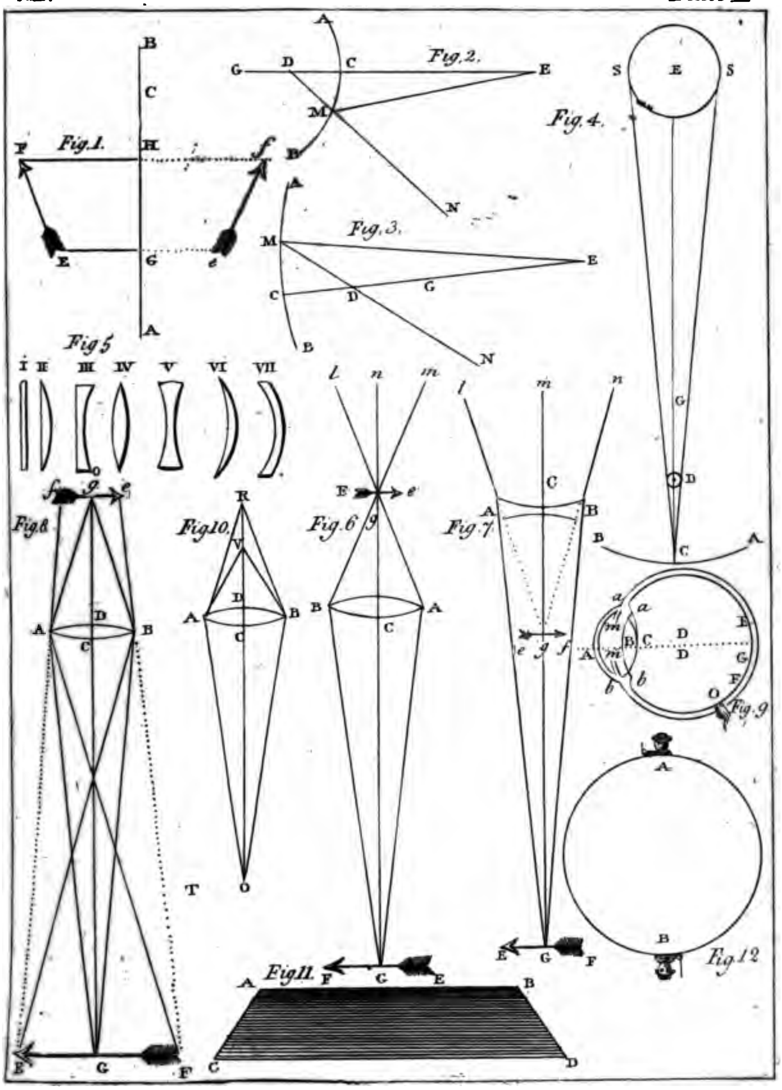
Fig.1.
Fig.2.
Fig.3.
Fig.4.
Fig.5
I II III IV V VI VII
Fig.6
Fig.7
Fig.8
Fig.9
Fig.10
Fig.11
Fig.12

to any body, holding it faſt at the other end, that thread will be ſtretched out into a ſtraight line, and that line will be vertical. Maſons employ a ſmall cord, with a leaden ball at one end, which they call a *plummet*, to direct the perpendicularity of the walls which they raiſe; for theſe, to be ſolid, muſt be vertical.

All the floors of a houſe ought to be ſo level, that the vertical line ſhall be perpendicular to them; the floor, in that caſe, is ſaid to be horizontal; and you will pleaſe to remember, that a horizontal plane is always that to which the vertical line is perpendicular. When you are in a perfect plane, bounded by no mountain, it's extremities are termed the *horizon*, a Greek word, which ſignifies the boundary of ſight; and this plane then repreſents a horizontal plane, juſt as the ſurface of a lake.

We make uſe of ſtill another term to expreſs what is horizontal. We ſay that ſuch a ſurface or line is *level*. We likewiſe ſay, that two points are on the level, when a ſtraight line, paſſing through theſe two points, is horizontal, ſo that the vertical, or plumb line, ſhall be perpendicular to it. But two points are not on the level, when the ſtraight line, drawn through theſe points, is not horizontal; for then one of them is more elevated than the other.

This is the caſe with rivers; their ſurface has a declivity; for were it horizontal, the river would be ſtagnant, and run down no longer, whereas all rivers re continually flowing toward places leſs elevated. iere are inſtruments, by means of which we can aſcertain,

aſcertain, whether two points are on the ſame level, or which is the higher, and by how much. This inſtrument is called a *level*, and the application of it is called the art of levelling.

Were you to draw a ſtraight line from any point, in your apartment at Berlin, to a given point in your apartment at Magdeburg, you might, by means of ſuch an inſtrument, aſcertain, whether this line were horizontal, or whether one of theſe points were more or leſs elevated than the other. I believe the point at Berlin would be more elevated than that at Magdeburg: and I found this opinion on the courſe of the rivers Sprée, Havel, and Elbe. As the Sprée runs into the Havel, it muſt, of courſe, be higher; and, for the ſame reaſon, the Elbe muſt be lower than the Havel: Berlin, therefore, ſtands higher than Magdeburg, provided you compare two points at an equal degree of elevation from the ground; for were a ſtraight line to be drawn from the ſtreet pavement at Berlin to the pinnacle over the dome at Magdeburg, that line would perhaps be horizontal.

Hence you ſee how uſeful the art of taking levels is, when the conducting of water is concerned. For as water can run only from a more to a leſs elevated ſituation, before digging a canal, you muſt be well aſſured, that one of the extremities is more elevated than the other, and this is diſcovered by taking the level.

In building a city, the ſtreets ſhould be ſo diſpoſed, as that, by means of a declivity on one ſide, the water may run off. It is otherwiſe in the conſtruction

tion of houses, the floors of which should be perfectly horizontal, and without the smallest declivity, because there is no water to be discharged, except in the floors of stables, which are constructed with a gentle declivity. Astronomers take great pains to have the floors of their observatories perfectly level, to correspond with the real horizon in the heavens. The vertical line, produced upward, marks the zenith.

27th August, 1760.

LETTER XLVIII.

Reply to certain Objections to the Earth's spherical Figure, derived from Gravity.

YOU know well that the figure of the earth is nearly that of a globe. It has, indeed, been demonstrated, that it's form is not perfectly spherical, but somewhat flattened toward the poles. The difference, however, is so trifling, that it does not at all affect the object I have in view. Neither does the difference of mountain and valley excite any solid objection to it's globular figure; for it's diameter being 1720 German miles,* whereas the highest mountains being scarcely half a mile† in height, sink into nothing, compared to this prodigious mass.

The ancients had a very imperfect notion of the

* 7900 miles English.

† About 12,000 feet, or 2 ^{3} miles English.

real

real figure of the earth. It was in general confider-ed as a huge maffy fubftance A B C D (*plate* II. *fig.* 11.) flattened above as A B, and covered partly with earth, partly with water. According to their idea, the furface A B alone was habitable; and it was im-poffible to go beyond the points A and B, which they confidered as the extremities of the world. When, in the progrefs of difcovery, it was found that the earth was nearly fpherical, and univerfally habitable, fo that there were upon the globe fpots diametrically oppofite to us, the inhabitants of which are therefore called our *antipodes*, becaufe their feet are turned directly toward ours; this opinion met with fuch violent contradiction, that certain fathers of the church reprefented it as a dreadful herefy, and thundered out anathemas againft all who believed in the exiftence of the antipodes. A man, however, would now pafs for an idiot, who would call it in queftion; efpecially fince the opinion has been con-firmed by the experience of navigators, who have actually more than once failed round the globe. But another difficulty here prefents itfelf, the folution of which muft affift us in difcovering the real direction of gravity.

If the circle A B (*plate* II. *fig.* 12.) fay they, re-prefents the earth, and we are at A, our antipodes will be diametrically oppofite, at B. As we, then, have the head upward, and the feet downward, our antipodes muft have the feet upward and the head downward, fuppofing thefe words to indicate the fame direction as when we pronounce the fame words

LETTER L.

Different Action of Gravity with respect to certain Countries and Distances from the Centre of the Earth.

OU are now sensible that all bodies are forced directly towards the centre of the earth, and licularly to it's surface by their gravity: the icular lines at the surface of our globe are acgly considered as the directions of the power avity.

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With ſtrict propriety is the term *power* applied to gravity, as every thing capable of putting a body in motion is expreſſed by that name. Thus we aſcribe power to horſes, becauſe they are able to draw along a chariot; or to the current of a river, or to the wind, becauſe by their means mills may be put in motion. There can be no doubt, therefore, that gravity is a power, as it forces bodies downward: and we are abundantly ſenſible of the effect of this power, by the preſſure which we feel when we carry a load.

Now, in every power two things are to be conſidered: firſt, the direction in which it acts, or forces along bodies; and, ſecondly, it's quantity, which is eſtimated by the effect it produces. As to the direction of gravity, it is ſufficiently known, for we are ſure that it forces all bodies toward the centre of the earth, or, which amounts to the ſame thing, that it acts perpendicularly to the ſurface of our globe.

It remains, therefore, that we examine it's quantity. This power is always determined by the weight of every body,* and as bodies differ greatly with reſpect

* In order to form an exact idea of the weight of a body, it muſt be recollected, that gravity impreſſes, or has a tendency to impreſs, on every particle of bodies, in an inſtant, a certain velocity, with which they would fall, if they were not ſupported; and that, abſtracting the influence of the air, this velocity would be the ſame for each of the particles of bodies, whatever be their ſubſtance. This being laid down, we muſt underſtand by the weight of a body the effort neceſſary to prevent it from falling; and it is evident that, in order to this, it is neceſſary to deſtroy the velocity

 which

ſpect to weight, thoſe which are heavieſt are likewiſe forced downward with the greateſt violence. It has been aſked, Whether the ſame body, tranſported to a different place of the globe, preſerves always the ſame weight? I ſpeak of bodies which loſe nothing by evaporation. It has been demonſtrated, by undoubted experiments, that the ſame body weighs ſomewhat leſs toward the equator, than toward the poles of the earth.

It will readily occur to you, that it is impoſſible to aſcertain this difference by the exacteſt balance, becauſe the ſtandard weights employed for determining the weight of matter in bodies, undergo the

which gravity has impreſſed on every particle. This effort muſt, therefore, be equal to the ſum of the velocities of all theſe particles. Hence it may be eaſily concluded, that bodies the moſt compact, that is, thoſe whoſe particles are the cloſeſt, and which, conſequently, contain a greater number of them in the ſame bulk, will weigh more than others, becauſe the weight being the ſum of the velocities impreſſed on each particle, that ſum muſt be ſo much greater, as there are more material particles contained in the maſs of the body.

From what I have juſt ſaid, "we ſee the neceſſity of carefully "diſtinguiſhing between the effect of gravity and that of weight: "the former is the power of tranſmitting, or a tendency to tranſ-"mit into every particle of matter a certain velocity, which is ab-"ſolutely independent on the number of material particles; and "the ſecond is the effort which muſt be exerciſed to prevent a "given maſs from obeying the law of gravity. *Weight*, accord-"ingly, *depends on the maſs, but gravity has no dependance at all upon* "*it.*"

I thought myſelf obliged to enter thus minutely into the ſub-as the notions commonly entertained of it are not very exact.

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ſame variation. Thus a maſs, which with us might weigh 100 pounds, being tranſported to the equator, would ſtill nominally be 100 pounds weight, but the effort will be ſomewhat leſs than here. This variation has been diſcovered by the effect itſelf of the power of gravity, which is the velocity of the deſcent, for it is found that the ſame body, under the equator, does not deſcend with ſo great velocity as in high latitudes. It is certain, therefore, that the ſame body, being tranſported to different places of the earth, undergoes a little change as to weight.

Let us now return to the aperture made in the earth through it's centre; it is clear, that a body at the very centre muſt entirely loſe it's gravity, as it could no longer move in any direction whatever, all thoſe of gravity tending continually toward the centre of the earth. Since, then, a body has no longer gravity at the centre of the earth, it will follow that, in deſcending to this centre, it's gravity will be gradually diminiſhed; and we accordingly conclude, that a body, penetrating into the bowels of the earth, loſes it's gravity, in proportion as it approaches the centre. You muſt be ſenſible, then, that neither the intenſity nor the direction of gravity is a conſequence from the nature of every body, as not only it's intenſity is variable, but likewiſe it's direction, which, on paſſing to the antipodes, becomes quite contrary.

Having travelled, in idea, to the centre of the earth, let us return to it's ſurface, and aſcend to the ſummit of the loftieſt mountains. We ſhall obſerve there no fenfible change in the gravity of bodies, though there is very good reafon to believe that the weight of a body diminifhes in proportion as it removes from the earth. You have but to imagine a body gradually removing from our globe, till it reached the fun, or one of the fixed ftars, it would be ridiculous to think that fuch a body muft fall back to the earth, as it is almoft a nothing compared to thefe ftars. Hence, then, it may be concluded, that a body in removing from the earth muft undergo a diminution of gravity, which will become fmaller and fmaller, till at laft it wholly difappear.

There are reafons, however, which demonftrate, that a body removed to the diftance of the moon, will ftill have fome weight, though 3600 times lefs than it had on the earth. Let us conceive fuch a body to weigh 3600 pounds on the earth, no one, furely, is capable of fupporting it here; but convey it to the diftance of the moon, and I fhall engage to fupport it with one of my fingers, for then it will weigh only one pound; and farther removed, would weigh ftill lefs. We are certain, therefore, that gravity is a power which forces all bodies toward the centre of the earth, that this power acts with the greateft force at the furface of the earth, and is diminifhed in proportion as it removes from thence, whether by penetrating toward the centre, or rifing above the furface of the globe. I have ftill much to fay on this fubject.

30th Auguft, 1760.

LETTER

LETTER LI.

Gravity of the Moon.

I HAVE faid that a terreftrial body, placed at the diftance of the moon, would be reduced to the 3600th part of it's weight, or, in other words, would be forced toward the centre of the earth with a power 3600 times lefs than it has at the furface of the globe. This power, however, would be fufficient to make it defcend to the earth, if it were no longer fupported. It is true we are incapable of proving this by any experiment, as no means exift of raifing ourfelves to fuch a height. There is, however, a body at that height, the moon: fhe muft, therefore, be fubject to this effect of gravity, and yet we fee fhe does not fall to the earth.

To this I anfwer, that if the moon were at reft, fhe would certainly fall, but the rapid motion which carries her along prevents her falling. There are experiments which prove the folidity of this anfwer. A ftone dropped from the hand, without having any motion impreffed upon it, falls immediately, in the direction of a ftraight vertical line; but if you throw this ftone, impreffing on it a motion which forces it out of that direction, it does not fall immediately downward, but moves in a curve line before it reaches the earth, and this will appear more fenfibly in proportion to the velocity impreffed upon it.

A cannon ball, difcharged in a horizontal direction, does not come to the earth till it has got to a confiderable diftance; and were it fired from the top of a high mountain, it might, perhaps, fly feveral miles before it reached the ground. If the direction of the cannon is farther elevated, and the quantity and ftrength of the powder increafed, the ball will be carried much farther. This might be carried fo far, that the ball fhould not light till it had reached the antipodes: nay, farther ftill, till it fhould not fall at all, but return to the place where it was fhot off, and thus perform a new tour round the globe. It would thus be a little moon, making it's revolutions round the earth like the real moon.

You will now pleafe to reflect on the height of the moon, and the prodigious velocity with which fhe moves, and you will no longer be furprifed that fhe fhould not fall to the earth, though forced by gravity toward it's centre. There is another reflection which will place this in a clearer light. We have only to confider the path defcribed by a ftone thrown, or a cannon ball fhot off, in an oblique direction. It is always a curve, fuch as reprefented in the annexed figure (*plate* III. *fig.* 3).

Let A be the fummit of a mountain from which the cannon ball is fired off, which, after having moved in the direction A E F B, falls to the ground at B; and the path which it defcribes is a curve line. I remark, then, that if the ball were not heavy, that is, if it were not forced toward the earth by the power of gravity, it would not fall, though left to itfelf, as gravity is the only caufe of it's defcent;

much

much leſs, being fired off at A, as repreſented in the figure, would it ever fall to the ground. Hence we ſee, it is gravity that brings it down to the ground, after having deſcribed the curve A E F B; gravity, therefore, directs it's path in the curve A E F B; and if it were deſtitute of gravity, the ball would not deſcribe a curve, but proceed forward in the direction of the ſtraight line A C, the direction in which it was fired off.

This being laid down, let us attend to the moon, which aſſuredly does not move in a ſtraight line; her path muſt of neceſſity be a curve, as ſhe always preſerves nearly the ſame diſtance from us, and that curve almoſt a circle, ſuch as you would deſcribe round the earth, with a radius equal to the moon's diſtance.

It is very reaſonable to demand, Why the moon does not move in a ſtraight line? But the anſwer is obvious; for as gravity occaſions the curve direction of the path purſued by a ſtone thrown, or a cannon ball fired off, there is good ground for maintaining, that gravity acts likewiſe upon the moon, forcing her toward the earth; and that this gravity occaſions alſo the curve direction of her orbit. The moon, then, has a certain weight, ſhe is, of conſequence, forced toward the earth; but this weight is 3600 times leſs than it would be at the ſurface of the earth. This is not merely a probable conjecture, but a truth demonſtrated. For this gravity being ſuppoſed, we are enable to determine, on the moſt eſtabliſhed mathematical

thematical principles, the path which the moon muſt purſue; and this is found perfectly to agree with that in which ſhe actually does move; and this is a complete demonſtration of the truth of the aſſertion.

1ſt September, 1760.

LETTER LII.

Diſcovery of univerſal Gravitation by Newton.

GRAVITY, then, or weight, is a property of all terreſtrial bodies, and it extends, likewiſe, to the moon. It is in virtue of gravity that the moon preſſes toward the earth; and gravity regulates her motion juſt as it directs that of a ſtone thrown, or of a cannon ball fired off.

To *Newton* we are indebted for this important diſcovery. This great Engliſh philoſopher and geometrician, happening one day to be lying under an apple-tree, an apple fell upon his head, and ſuggeſted to him a multitude of reflections. He readily conceived that gravity was the cauſe of the apple's falling, by overcoming the force which attached it to the branch. Any perſon whatever might have made the ſame reflection; but the Engliſh philoſopher purſued it much farther. Would this force have always acted upon the apple, had the tree been a great deal higher? He could entertain no doubt of it.

But had the height been equal to that of the moon? Here

Here he found himſelf at a loſs to determine whether the apple would fall or not. In caſe it ſhould fall, which appeared to him, however, highly probable, ſince it is impoſſible to conceive a bound to the height of the tree, at which it would ceaſe to fall, it muſt ſtill have a certain degree of gravity forcing it toward the earth; therefore, if the moon were at the ſame place, ſhe muſt be preſſed toward the earth by a power ſimilar to that which would act upon the apple. Neverthelefs as the moon did not fall on his head, he conjectured that motion might be the cauſe of this, juſt as a bomb frequently flies over us, without falling vertically.

This compariſon of the motion of the moon to that of a bomb, determined him attentively to examine this queſtion; and, aided by the moſt ſublime geometry, he diſcovered, that the moon in her motion was ſubject to the ſame laws which regulate that of a bomb, and that if it were poſſible to hurl a bomb to the height of the moon, and with the ſame velocity, the bomb would have the ſame motion as the moon, with this difference only, that the gravity of the bomb at ſuch a diſtance from the earth, would be much leſs than at it's ſurface.

You will ſee, from this detail, that the firſt reaſonings of the philoſopher on this ſubject were very ſimple, and ſcarcely differed from thoſe of the clown; but he ſoon puſhed them far beyond the level of the clown. It is, then, a very remarkable property of the earth, that not only all bodies near it, but thoſe alſo which are remote, even as far as to the diſtance

of

of the moon, have a tendency toward the centre of the earth, in virtue of a power which is called gravity, and which diminishes in proportion as bodies remove from the earth.

The English philosopher did not stop here. As he knew that the other planets are perfectly similar to the earth, he concluded, that bodies adjacent to each planet possess gravity, and that the direction of this gravity is toward the centre of such planet. This gravity might be greater or less there than on the earth; in other words, that a body of a certain weight with us, transported to the surface of any planet, might there weigh more or less.

Finally, this power of gravity of each planet extends, likewise, to great distances around them; and as we see that Jupiter has four satellites, and Saturn five, which move round them just as the moon does round the earth, it could not be doubted, that the motion of the satellites of Jupiter was regulated by their gravity toward the centre of that planet; and that of the satellites of Saturn by their gravitation toward the centre of Saturn. Thus, in the same manner as the moon moves round the earth, and their respective satellites move round Jupiter and Saturn, all the planets themselves move round the sun. Hence *Newton* drew this illustrious and important conclusion: That the sun is endowed with a similar property of attracting all bodies toward it's centre, by a power which may be called *solar gravity*.

This power extends to a prodigious distance around him, and far beyond all the planets, for it is this power which modifies all their motions. The ſame great philoſopher diſcovered the means of determining the motion of bodies from the knowledge of the power by which they are attracted to a centre; and as he had diſcovered the powers which act upon the planets, he was enabled to give an accurate deſcription of their motion. In truth, before he aroſe, the world was in a ſtate of profound ignorance reſpecting the motion of the heavenly bodies; and to him alone we are indebted for all the light which we now enjoy in the ſcience of aſtronomy.

It is aſtoniſhing to think how much of their progreſs all the ſciences owe to an original idea ſo very ſimple. Had not *Newton* accidentally been lying in an orchard, and had not that apple by chance fallen on his head, we might, perhaps, ſtill have been in the ſame ſtate of ignorance reſpecting the motions of the heavenly bodies, and a multitude of other phenomena depending upon them.* This ſubject, undoubtedly, is altogether worthy of your attention, and ſhall therefore be reſumed in a future letter.

3d September, 1760.

* *Newton* was aſked one day, How he had diſcovered the ſyſtem of the univerſe? *By continually thinking upon it*, replied he. This anecdote has a greater air of probability than the ſtory of the apple.—*F. E.*

LETTER

LETTER LIII.

Continuation. Of the mutual Attraction of the heavenly Bodies.

THE Newtonian fyftem, you will eafily believe, made at firft a great noife, and with good reafon, as no one had hitherto hit upon a difcovery fo very fortunate, and which diffufed, at once, fuch clear light over every branch of fcience. It has been expreffed by feveral names, of which it is proper you fhould be informed, becaufe it is frequently the fubject of converfation.

It has been denominated, the fyftem of univerfal gravitation; for *Newton* maintained, that not only the earth, but all the heavenly bodies, in general, are endowed with this property, of attracting thofe which furround them, with a power fimilar to that of weight, or gravity: hence is derived the term *Gravitation*. This power is, however, totally invifible; for we fee nothing acting upon bodies, and preffing them toward the earth, and ftill lefs toward the heavenly bodies.

The loadftone, by which iron and fteel are attracted, without our being able to difcern the caufe, prefents a phenomenon fomewhat fimilar. Though it be now certain, that this is produced by a fubftance extremely fubtile, which penetrates through the pores of the loadftone and of the iron, it may, however, be affirmed, that the loadftone attracts iron, and that

iron

iron is attracted by it, provided this manner of ſpeaking does not exclude the true cauſe. It may likewiſe be affirmed, then, that the earth attracts all bodies that are near it, nay thoſe which are at very great diſtances; and we may conſider the weight, or gravity, of bodies, as the effect of the attraction of the earth, which acts even upon the moon.*

Again, the ſun, and all the planets, are endowed with a ſimilar power of attraction, which extends to all bodies. In conformity to this manner of ſpeaking, we ſay, that the ſun attracts the planets, and that Jupiter and Saturn attract their reſpective ſatellites; hence *Newton*'s ſyſtem has likewiſe been denominated, the ſyſtem of *Attraction*. As there can be no doubt that bodies very near the moon muſt likewiſe be preſſed to it by a power ſimilar to gravity, it may likewiſe be affirmed, that the moon, too, attracts adjoining bodies.

It was natural to ſuppoſe, that this attraction of the moon ſhould extend as far as the earth, though it muſt be, undoubtedly, very feeble, as we have ſeen

* So far is the exiſtence of a magnetic fluid from being undeniable, that it is highly improbable, if not abſurd. The various phenomena of magnetiſm may clearly be derived from two laws, or general facts; than which a greater ſimplicity can hardly be expected. If we recur to the agency of a fluid, we muſt gratuitouſly beſtow on it a number of properties; and, after all, we ſhall find it extremely difficult, I might ſay, impoſſible, to preſerve conſiſtency in our complicated hypotheſis; nor ſhall we ever be able, from our aſſumptive principles, to account for the facts obſerved. Such, at leaſt, has been the fate of the ſpeculations hitherto offered on the ſubject of magnetiſm.—*E. E.*

that

that of the earth upon the moon to be; now, the ſame philoſopher has placed this, alſo, beyond the reach of doubt, by demonſtrating that the flux and reflux of the waters of the ſea, of which I ſhall take occaſion to ſpeak afterwards, are cauſed by the attraction of the moon. It can no longer be doubted, therefore, that Jupiter and Saturn are reciprocally attracted by their reſpective ſatellites; and that the ſun itſelf is ſubject to the attraction of the planets, though this attractive power be exceedingly ſmall.

This is the origin of the ſyſtem of univerſal attraction, in which it is maintained, and with good reaſon, that not only does the ſun attract the planets, but is reciprocally attracted by each of them; nay, that all the planets exert their attractive power upon each other. The earth, then, is attracted, not only by the ſun, but alſo by all the other planets, though their power be almoſt imperceptible, compared to that of the ſun.

You will eaſily comprehend, that the motion of a planet, which is attracted not only by the ſun, but by the other planets, in however ſmall a degree, muſt be ſomewhat different from what it would have been, were it attracted by the ſun only; and that, conſequently, the attractions of the other planets muſt cauſe ſome ſmall derangement of that motion. Now theſe derangements are, likewiſe, confirmed by experience; and this has carried the ſyſtem of univerſal attraction to the higheſt poſſible degree of certainty, ſo that no one now preſumes to diſpute it's truth.

I muſt,

I muſt likewiſe remark, that comets, too, are ſubject to this law; that they are principally attracted by the ſun, whoſe action regulates their motion; but that they, likewiſe, feel the attractive power of all the planets, eſpecially when they are not very diſtant from them. It is a general rule, as we ſhall ſee afterwards, that the attraction of all the heavenly bodies diminiſhes in proportion to the diſtance, and increaſes in proportion to the nearneſs. Now, comets, likewiſe, are endowed with a power, by which other bodies are attracted toward them, and ſo much the more ſenſibly, as they approach nearer. When, therefore, a comet paſſes ſomewhat more cloſely to a planet, it may derange the motion of that planet by it's attractive power; and it's own will likewiſe be diſturbed by that of the planet. Theſe conſequences are verified by real obſervation.

Examples might be adduced to prove, that the motion of a comet has been deranged by the attraction of the planets, near which it happened to paſs,*

* The comet of 1682, which ſhould have re-appeared in 1757, underwent, from the attractive powers of Jupiter and Saturn, near which it paſſed, a conſiderable derangement, which retarded it's appearance nearly two years. Mr. *Clairaut* calculated, theoretically, the perturbations which it's motion muſt have ſuffered, and predicted the return of that comet, with a degree of exactneſs, which conſtitutes a convincing proof in favour of the ſyſtem of gravitation. There was, however, an error of two months. But Mr. *de la Place* has ſince demonſtrated, that it would have been much leſs, had we then been able to calculate the perturbations of Jupiter and Saturn, with as much exactneſs as it now can be done.—*F. E.*

and that the motion of the earth, and of the other planets, has already undergone ſome derangement, from the attraction of comets.

The fixed ſtars being bodies ſimilar to the ſun, are likewiſe endowed, no doubt, with an attractive power, but their enormous diſtance prevents our feeling any ſenſible effect from it.

5th Sept. 1760.

LETTER LIV.

Different Sentiments of Philoſophers, reſpecting univerſal Gravitation. The Attractioniſts.

IT is eſtabliſhed, then, by reaſons which cannot be controverted, that an univerſal gravitation pervades all the heavenly bodies, by which they are attracted toward each other; and that this power is greater in proportion to their proximity.

This fact is inconteſtable, but it has been made a queſtion, Whether we ought to give it the name of *impulſion*, or *attraction?* The name, undoubtedly, is a matter of indifference, as the effect is the ſame. The aſtronomer, accordingly, attentive only to the effect of this power, gives himſelf little trouble to determine, whether the heavenly bodies are impelled toward each other, or whether they mutually attract one another: and the perſon, who examines the phenomena only, is unconcerned, whether the earth attracts

tracts bodies, or whether they are impelled toward it, by ſome inviſible cauſe.

But, in attempting to dive into the myſteries of nature, it is of importance to know, if the heavenly bodies act upon each other by impulſion, or by attraction; if a certain ſubtile inviſible matter impels them toward each other, or if they are endowed with a ſecret, or occult, quality, by which they are mutually attracted? On this queſtion philoſophers are divided. Some are of opinion, that this phenomenon is analogous to an impulſion; others maintain, with *Newton*, and the Engliſh in general, that it conſiſts in attraction.

It muſt be obſerved, that the terms *attract*, and *draw*, are not perfectly ſynonymous; that, accordingly, it is not to be ſuppoſed, there is an intermediate body between the ſun and the earth.

The Engliſh, and thoſe who have adopted the ſame opinion, explain it in this manner. They maintain, that the quality of mutual attraction is proper to all bodies; that it is as natural to them as magnitude, and that it is a ſatisfying ſolution of the queſtion, That the Creator willed this mutual attraction of bodies. Had there been but two bodies in the univerſe, however remote from each other, they would have had, from the firſt, a tendency toward each other, by means of which they would have, in time, approached and united. Hence it follows, that the greater a body is, the more conſiderable is the attraction which it exerts upon others; for, as this quality is effential to matter, the more of it any body contains, the greater is it's attractive force.

As the fun, therefore, confiderably furpaffes all the planets in magnitude, it's attractive force muft be much greater than theirs. They likewife remark, that the mafs of Jupiter, being much greater than that of the earth, the attractive force which he exercifes over his fatellites, is much more powerful than that with which the earth acts upon the moon.

According to this fyftem, the gravity of bodies on the earth, is the refult of all the attractions exercifed upon them by the particles of our globe; and if it contained more matter than it actually does, it's attraction would become more powerful, and the gravity of bodies would be increafed. But if, on the contrary, the mafs of the earth fhould happen, by fome accident, to be diminifhed, it's attractive force, too, would be diminifhed, as well as the gravity of bodies, at it's furface.

It has been objected to thefe philofophers, that, on their hypothefis, any two bodies, whatever, at reft, for inftance, on a table, muft attract each other, and, confequently, approach. They admit the confequence, but they infift, that, in this cafe, the attraction would be too fmall to produce any fenfible effect; for, if the whole mafs of the earth, by it's attractive force, produces in every body, only that effect which we perceive in the weight of a body, a mafs many millions of times fmaller than the earth, will produce an effect as many times fmaller.

It

It muſt readily be admitted, that if the weight of a body became many millions of times leſs, the effect of gravity upon it muſt be reduced to almoſt nothing: attraction, therefore, cannot be perceptible, except in bodies of very great magnitude. The partizans of the ſyſtem of gravitation, therefore, are not vulnerable on this ſide, and they produce, in ſupport of their opinion, an experiment made in Peru, by the French academicians,* in which they perceived the effect of a ſlight attraction of a prodigious mountain on adjacent bodies. In adopting, therefore, the ſyſtem of attraction, we need to be under no apprehenſion of it's leading us to falſe conſequences; and it has hitherto been always confirmed by the new facts which have been diſcovered.

7th September, 1760.

LETTER LV.

Power by which the Heavenly Bodies are mutually attracted.

YOU are well acquainted with the property of the loadſtone, that of attracting iron. You have ſeen ſmall bits of iron and ſteel, ſuch as needles, when

* The academicians ſent to Peru, in 1735, to meaſure a degree of the meridian, obſerved a deviation of 8" in the plumb-line of their quadrant, occaſioned by the attraction of *Pichencha*, a mountain near the place where they were making their obſervations. Dr. *Maſkelyne* has more recently made obſervations for aſcertaining the effect of the attraction of the mountains of Scotland.—*F. E.*

placed near the loadſtone, move to it with a force proportioned to their proximity. As you ſee nothing that impels them toward the loadſtone, we ſay that the loadſtone attracts them, and this phenomenon we call *attraction*. It cannot be doubted, however, that there is a very ſubtile, though inviſible, matter, which produces this effect, by actually impelling the iron toward the loadſtone; but as modes of expreſſion are regulated by appearances, it has become cuſtomary to ſay, that the loadſtone attracts iron.

Though this phenomenon be peculiar to the loadſtone and iron, it is perfectly adapted to convey an idea of the ſignification of the word attraction, which philoſophers ſo frequently employ. They allege, then, that all bodies, in general, are endowed with a property ſimilar to that of the loadſtone, and that they all mutually attract; but that this effect becomes not perceptible, unleſs they are very great, and cannot be perceived when they are ſmall.

However great, for example, a ſtone may be, it exerciſes no ſenſible attraction on other bodies adjacent to it, becauſe it's power is too ſmall. But if it's maſs were to increaſe, and to become many thouſands of times greater, it's effect would, at length, become perceptible. It has already been remarked, that, from actual obſervation, it was found, that a lofty mountain in Peru had produced attraction, though, indeed, in a very ſmall degree. A mountain ſtill greater, would produce, therefore, a more ſenſible attraction; and a body much greater, ſuch

as

as the whole globe, would attract others with a force proportionably greater; and this force would be, precisely, the gravity with which we see that they are actually impelled toward the earth.

According to this system, then, the gravity which obliges all bodies to descend, is nothing else but the result of the attraction of the whole mass of the earth. If this mass were greater, or less, the gravity, or weight, of bodies would be proportionably greater or less. Hence it follows, that all the other great bodies in the universe, as the sun, the planets, and the moon, are endowed with a similar attractive power, but greater or less, in proportion as they themselves are so.

As the sun is many thousands of times greater than the earth, his attractive power exceeds that of the earth, so many thousand times. The mass of the moon is calculated to be forty times less than that of the earth: it will follow, that her attractive force is so many times less; and the same rule applies to all the heavenly bodies.

9th September, 1760.

LETTER LVI.

The same Subject continued.

IN virtue of the system of attraction, or universal gravitation, each of the heavenly bodies attracts all the rest, and is reciprocally attracted by them.

In order to form a judgment of the force with which theſe bodies attract the others, we have only to conſider two bodies, whoſe attraction is mutual. And here we muſt attend to three things; firſt, to the body attracting; ſecondly, to the body attracted; and, finally, to their diſtance; for on theſe three circumſtances the attractive power depends.

Let A (*plate* III. *fig.* 4,) be the attracting body, and B the body attracted; both of them ſpherical, the heavenly bodies being nearly of this figure. Take for their diſtance that of their centres A and B, that is, the ſtraight line A B. Now, with reſpect to the maſs of the attracting body A, it muſt be remarked, that the greater it is, the greater alſo will be it's power to attract the body B. Conſequently, if A were twice as great as B, this laſt would feel an attraction, twice as powerful, exerciſed over it, by the other; if it were three times as great, the effect would be triple, and ſo on, always ſuppoſing the diſtance of their centres to be the ſame.

If, then, the earth contained more or leſs matter than it actually does, it would attract all adjacent bodies, with greater or leſs force, or their weight would be increaſed or diminiſhed. And, as the earth itſelf is attracted by the ſun, the ſame thing might be affirmed as to it, ſhould the maſs of that luminary happen to change. As to the attracted body B, ſuppoſing the attracting body A, and the diſtance A B, to continue the ſame, it is to be remarked, that the greater or ſmaller it's maſs is, the greater or leſs, alſo, is the power with which it is attracted to-

ward

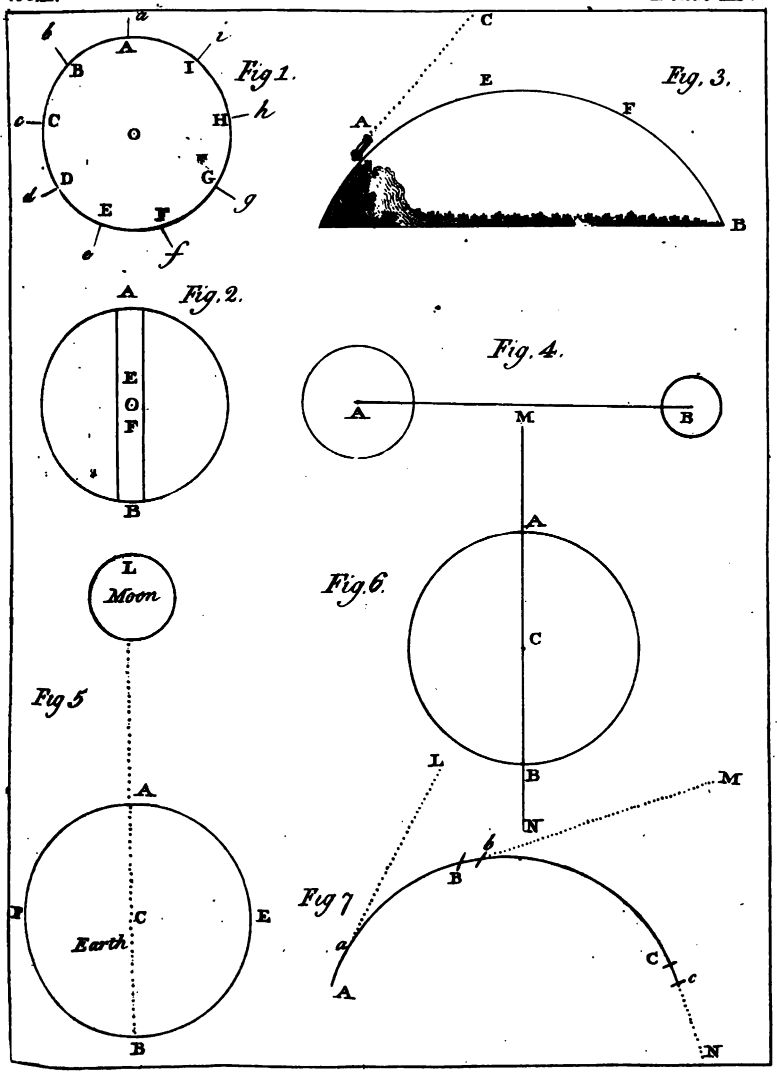
Fig 1.
a
b
i
A
B
I
c
C
O
H
h
D
G
d
g
E
F
e
f
C
Fig. 3.
E
F
A
B
Fig. 2.
A
E
O
F
B
Fig. 4.
A
M
B
L
Moon
A
Fig. 6.
C
Fig 5
B
N
L
M
A
b
B
Fig 7
P
C
E
Earth
a
A
C
c
B
N

ward A. Thus, if the body B were twice as great, it would be attracted toward A, with double the force; if three times greater, with triple the force, and fo on.

In order more clearly to elucidate this remark, we have only to fubftitute the earth in the place of the attracting body A; then the force with which the body B is attracted, is nothing elfe but the weight of that body. Now, it is demonftrated, that the greater or fmaller the body B is, the greater or lefs, alfo, is it's gravity; hence it follows, that while the attracting body A, and the diftance, A B continue the fame, the attraction which B feels, precifely follows the magnitude of that body. To exprefs this circumftance, mathematicians employ the term *proportional*; thus they fay, The body B is attracted by the body A, with a force proportional to it's mafs; the meaning of which is, that if the mafs of body B were twice, thrice, or four times greater, the attractive power would be precifely fo many times increafed. Thus, with refpect to the attracting body A, they fay, that the power which it exercifes over the body B, is proportional to it's mafs, fo long as that of B, and the diftance A B continue the fame.

I muft farther obferve, that when we fpeak of the quantity of the attracting body A, or of the attracted body B, we mean the quantity of matter which each contains, and not their magnitude merely. You will recollect, that bodies differ confiderably, in this refpect, and that there are fome, which, in a very fmall compafs, contain a great deal of matter, gold, for example,

example, while others, ſuch as air, contain very little in a great ſpace. When, therefore, we here ſpeak of bodies, we are always to be underſtood as referring to the quantity of matter which they contain: this is what we mean by their maſs.

All that now remains is, to examine the third circumſtance, namely, the diſtance A B of the two bodies, ſuppoſing them to continue always the ſame. It muſt be obſerved, that as the diſtance A B increaſes, the attraction diminiſhes: and that as they approach nearer, it increaſes: but in conformity to a law, which it is not ſo eaſy to expreſs. When the diſtance becomes twice as great, the force with which the body B is attracted toward the body A, will be twice two, or four times leſs; and for triple the diſtance, the attraction becomes three times three, that is nine times leſs. If the diſtance becomes four times greater, the power of attraction becomes four times four, that is ſixteen times leſs, and ſo on. Finally, for a diſtance a hundred times greater, the power of attraction will be a hundred times a hundred, or ten thouſand times leſs. From this it follows, that at very great diſtances, it muſt become altogether imperceptible. And reciprocally, when the diſtance A B is very ſmall, the attraction may be very conſiderable, though the bodies may be of no great magnitude.

th September, 1760.

LETTER

LETTER LVII.

The fame Subject continued.

I HAVE now demonftrated, that when a body B is attracted by a body A, the power of attraction is proportional to the mafs of the attracting body A, and to that of the attracted body B; but it depends, to fuch a degree, on the diftance of thefe bodies, that if it fhould become twice, thrice, four or five times greater, the power of attraction would become four, nine, fixteen, or twenty-five times lefs.

In order to afcertain the rule of thefe quantities, we muft multiply, into itfelf, the number which marks how many times the diftance is increafed, and the product will fhew how many times lefs the power of attraction has become. To put this rule in it's cleareft light, it muft be obferved, that when we multiply a number into itfelf, the product, refulting from it, is called it's *fquare*. Thus, to find thefe fquares, we muft multiply the numbers by themfelves, as below.

	1	2	3	4	5	6	7	8	9	10
Multiplied by	1	2	3	4	5	6	7	8	9	10
Square	1	4	9	16	25	36	49	64	81	100

	11		12
Multiplied by	11	Multiplied by	12
	11		24
	11		12
Square	121	Square	144

It

It is clear, from this laſt example, that the ſquare of number 12 is 144; and if you wiſh to know the ſquare of any number whatever, ſay 258, you muſt multiply that number by itſelf, as in the following ſeparation:

```
   258
   258
  ----
  2064
 1290
 516
 -----
 66564
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From which we ſee, that the ſquare of 258 is 66564; and the ſquares, of all numbers whatever, may be calculated in like manner.

As the diſtance of bodies, then, muſt be multiplied by itſelf, it is evident, that the power of attraction diminiſhes, as much as the ſquare of the diſtance increaſes: or, that the ſquare of the diſtance becomes as many times greater, as the power of attraction is diminiſhed.

In treating ſubjects of this nature, mathematicians employ expreſſions, whoſe ſignification it is proper you ſhould know, becauſe they ſometimes occur in the courſe of converſation. If the attractive power increaſed in proportion to the ſquare of the diſtance, we would call it *proportionally* to the ſquare of the diſtance; but as the direct contrary takes place, and as the attractive power diminiſhes as the ſquare of the diſtance increaſes, we employ the term *recipro-*

cally,

cally, to exprefs this contrariety, faying, that the power is reciprocally proportional to the fquare of the diftance.* It is a geometrical mode of expreffion, the meaning of which you perfectly comprehend, and it refers to what I have juft been attempting to explain.

In order to judge aright of the power which one body exercifes over another, you have only to remark, that this power is, firft of all, proportional to the mafs of the attracting body: then, to that of the body attracted; and finally, reciprocally to the fquare of their diftance. Hence, it is evident, that though the earth, and the other planets, are likewife attracted toward the fixed ftars, this power muft be imperceptible, on account of their prodigious diftance.

Suppofing, therefore, the mafs of a fixed ftar to be equal to that of the fun, at equal diftances, the earth would be attracted toward it, with a force as great as toward the fun; but as the diftance of the fixed ftar is 400,000 times greater than that of the fun, the fquare of this number being 160,000,000,000, that is, a hundred and fixty thoufand millions, the power with which it acts upon our globe, is a hundred and fixty thoufand millions of times lefs than that of the fun; and, confequently, too feeble to produce any perceptible effect. For this reafon, the attractive power of the fixed ftars does not at all affect the earth's motion, nor that of the planets and the

* It is more cuftomary to fay, that attraction is in the direct ratio of the maffes of the attracting and attracted bodies; and in the inverfe ratio of the fquare of their diftance.—*F. E.*

moon;

moon; but it is that of the ſun which chiefly regulates their motions, becauſe his maſs exceeds many thouſands of times the maſs of each planet.

When, however, two planets approach, ſo that their diſtance becomes leſs than that of the ſun, their attractive power increaſes, and may become ſufficiently perceptible to derange their motion. Such derangement has, in fact, been obſerved; and conſtitutes an irreſiſtible proof of the ſyſtem of univerſal gravitation. Accordingly, when a comet approaches very near to a planet, the motion of this laſt may be conſiderably affected by it.

13th September, 1760.

LETTER LVIII.

Motion of the heavenly Bodies. Method of determining it by the Laws of univerſal Gravitation.

FROM what has been ſaid, reſpecting the power by which all the heavenly bodies mutually attract each other, proportionally to their maſs and diſtance, you are enabled to comprehend, how their motions may be determined, and the real place of each body, at any given time, accurately aſſigned.

In this aſtronomy conſiſts; the object of which is an exact knowledge of the motions of the heavenly bodies, in order to be able to determine, for every inſtant of time, whether paſt or to come, the place which each of them muſt be, and in what place of the

the heavens it muſt appear, whether viewed from the earth, or any other point whatever of the univerſe.

The ſcience which treats of motion in general, is named *mechanics*, or *dynamics*. It's object is to determine the motion of all bodies whatever, animated by whatever power. This ſcience conſtitutes one of the principal branches of mathematics; and thoſe who apply to it, exert all their efforts to carry mechanics to the higheſt poſſible degree of perfection. The ſubjects about which this ſcience is converſant, are, however, ſo intricate, that there is hitherto no great ground of boaſting of our progreſs in the inveſtigation of them; and we muſt reſt ſatisfied with advancing ſtep by ſtep. Not many years are elapſed ſince we began to make any progreſs at all in this career, and what has been done is chiefly to be aſcribed to the academy of ſciences at Paris, which propoſes annual prizes to the beſt proficients in the proſecution of this ſcience.

The greateſt difficulty ariſes from the number of powers which act upon the heavenly bodies. If each of theſe were attracted toward only one ſingle point, there would be very little difficulty in the way; and the great *Newton*, who died in 1728, was the firſt who gave a complete demonſtration of the motion of two bodies which have a mutual attraction, in conformity to the law which I have laid down. In virtue of this law, were the earth attracted toward the ſun only, we ſhould be able perfectly, without reſearch, to determine it's motion. The ſame thing would apply to the other planets, Saturn, Jupiter,

Mars,

Mars, Venus, and Mercury, if they were attracted only by the ſun. But the earth being attracted, not only by him, but by all the other heavenly bodies, the queſtion becomes infinitely more complex and difficult, from the great diverſity of powers to which we muſt pay attention.* You may neglect, however, the powers with which it is attracted toward the fixed ſtars, becauſe, however enormous their maſſes may be, they are ſo prodigiouſly diſtant, that the power which they exerciſe upon the earth, may be conſidered as juſt nothing.

The motion of the earth, therefore, and of the other planets, will always be as perfectly the ſame, as if the fixed ſtars did not exiſt. Excepting, then, the power of the ſun, we have only to conſider the power with which the planets mutually attract each other. Now, theſe powers are extremely ſmall, compared to thoſe by which each planet is attracted toward the ſun, becauſe the maſs of the ſun is much greater than that of each planet.

As, however, theſe powers increaſe according as the diſtances diminiſh, ſo that a power four times greater correſponds to a diſtance twice leſs; and a

* They are uſually combined by three and three; that is, the effect reſulting from the attraction of two bodies upon a third is ſought. This celebrated problem, known by the name of the problem of three bodies, has been an object of the reſearches of all the great geometricians of our age; and though it has hitherto been reſolved only by an approximation to the truth, the moſt fortunate applications have, however, been made, ſuch as the theory of the moon, that of Jupiter, of Saturn, &c.—*F. E.*

power nine times leſs correſponds to a diſtance three times greater, and ſo on, according to the ſquares of the numbers, as I explained the ſubject in the preceding letter, it might be poſſible for two planets to approach ſo near, that their attractive power ſhould become equal to that of the ſun, nay, greatly exceed it.

Fortunately, this never takes place in our ſyſtem, and the planets always remain at ſuch a diſtance from each other, that their attractive power is ever incomparably ſmaller than that of the ſun. For this reaſon, without extending our views beyond what is thus certainly known, we may conſider every planet as attracted only by the power of the ſun, and by that it is eaſy to determine it's motion. This, however, can take place, only when we are diſpoſed to reſt ſatisfied with a reſult near the truth; for if we wiſh to have more exact information, we muſt attend to thoſe feebler powers with which the planets act upon each other; powers which really produce the little irregularities clearly obſerved by aſtronomers; and to the attainment of the perfect knowledge of theſe, is directed all the ſagacity of both aſtronomers and geometricians.

15th September, 1760.

LETTER LIX.

Syſtem of the Univerſe.

IN order the more clearly to elucidate what I have been advancing, reſpecting the motion of the heavenly bodies, and the powers which produce it, permit me to preſent to you, (*plate* IV. *fig.* 1.) the ſyſtem of the univerſe, or a deſcription of the heavenly bodies which compoſe it.

We muſt, firſt of all, obſerve, that the fixed ſtars are bodies entirely ſimilar to the ſun, and luminous of themſelves; that they are at a very great diſtance from that luminary; and alſo very diſtant from each other; and that every one of them is, perhaps, of equal magnitude with the ſun. You are already informed, that the fixed ſtar neareſt to us, is at leaſt 400,000 times more diſtant than the ſun. Each of the fixed ſtars ſeems deſigned to communicate light and heat, to a certain number of opaque bodies, ſimilar to our earth, and, undoubtedly, inhab[illegible] likewiſe, placed near them, but which we cann[illegible] on account of their prodigious diſtance.

Though it is impoſſible to aſcertain thi[illegible] obſervations, we muſt conclude it, fro[illegible] logy to the ſun, who ſerves to warm [illegible] nate the earth and the other plane[illegible] particularly, ſix of theſe bodies [illegible] ſtate of reſt, but each of them [illegible] in the direction of a curve [illegible]

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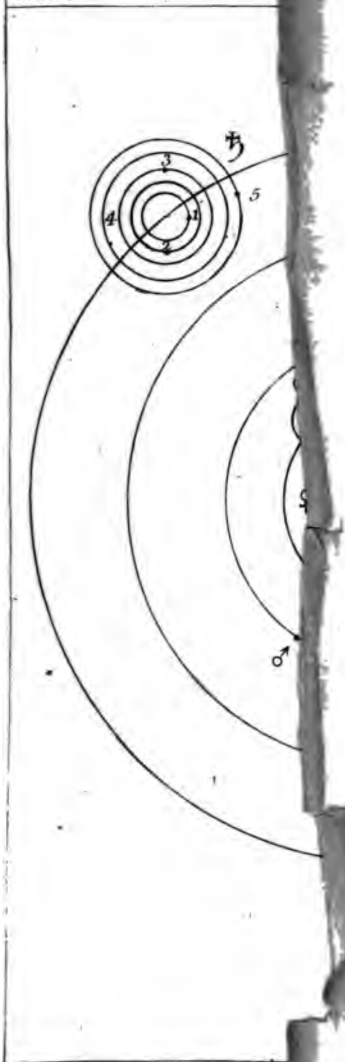

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from a circle, and which is called the planet's orbit. The sun himself is, nearly, in a state of rest, as well as all the fixed stars; the motion which they appear to have, being entirely owing to that of the earth.

I have, accordingly, represented on the annexed sheet, what is called the solar system, which contains all the opaque bodies that move round the sun, and derive from him all the benefits which he imparts to us. This sign ☉ (*plate* IV. *fig.* 1.) represents the sun at rest. You see, besides, six concentric circles, representing the orbits described by the planets in their motion round him.

That nearest to the sun is Mercury, marked by the sign ☿, and the black dot you see in the orbit represents the body of Mercury, who performs his revolution round the sun in about 88 days.

Next comes Venus, marked by ♀, who completes a revolution round the sun in seven months nearly.

The third circle is the orbit of the earth, marked by the sign ♁, and which completes a revolution round the sun in a year. We have no other meaning, in truth, to the word year, but the time employed by the earth in performing a revolution round the sun; and the duration of the common year nearly approaches to this solar year.

But while the earth is moving round the sun, there is another body moving round the earth, and keeping the direction of it's orbit; this is the moon, whose own circle, or orbit, is marked by ☽.

The two first planets, Mercury and Venus, have no visible bodies which attend them; neither has Mars ♂, which is the fourth, and performs his revolution in about two years.

The fifth circle is the orbit of Jupiter, marked by ♃, who performs his revolution in twelve years nearly. Round him move four satellites, represented in the plate, with their orbits, and marked by the figures 1, 2, 3, 4.

Finally, the sixth and last circle is the orbit of Saturn, marked thus, ♄, who employs almost thirty years in performing one revolution round the sun. This planet is attended, in his course, by five satellites, marked by the figures 1, 2, 3, 4, 5. Thus, then, the solar system consists of six primary planets, Mercury ☿, Venus ♀, the Earth ♁, Mars ♂, Jupiter ♃, Saturn ♄, and ten secondary planets or satellites, namely, the moon, the four attendants of Jupiter, and the five of Saturn.*

* To this enumeration must now be added, the planet discovered at Bath the 17th of March, 1781, by Mr. *Herschel*, and taken at first for a comet. It is more distant from the sun than Saturn, and it's orbit must be represented by a seventh circle, circumscribing all the others. The period of it's revolution is about 83 years. Tables of it's motion have been constructed, which represent already the observations with an exactness, that announces the perfection both of the instruments, and of the method of calculation.

It is admitted, that this star was seen in 1756, in the month of September, by Mr. *Mayer*, of Gottingen; but that astronomer took it for a fixed star, and having observed it only once, he could not ascertain it's motion: his determination agrees in other respects with the place which the tables assign to the planet of Mr. *Herschel*, This ſyſtem contains, beſides, ſeveral comets, the number of which is unknown. The figure on the plate repreſents one of them, whoſe orbit differs from that of the planets, becauſe it is drawn out into extreme length, ſo that a comet ſometimes approaches very near to the ſun, and ſometimes removes to ſuch an immenſe diſtance, as entirely to diſappear. Of comets it has been remarked, that one finiſhes his revolutions in his orbit, in about ſixty years; this is the one that was viſible laſt year. As to the other comets, it is certain, that they employ ſeveral centuries in performing one revolution in their orbits; and as, in paſt ages, no exact obſervations were made of them, we are totally in the dark with reſpect to their return. Of theſe, then, conſiſts the ſolar ſyſtem; and, moſt probably, every fixed ſtar has one ſimilar to it.*

17th September, 1760.

Herſchel, for that epoch. It bears the name of the perſon who diſcovered it.

The mean diſtances of the planets from the ſun, may be thus reſpectively expreſſed: that of Mercury by 4, that of Venus by 7, that of the earth by 10, that of Mars by 15, that of Jupiter by 52, that of Saturn by 95, and, finally, that of the planet *Herſchel* *(a)* by 191—*F. E.*

* Aſtronomers expect about 1790 the comet obſerved iu 1531, and in 1661, which they believe to be the ſame ſtar, and the period of which appears to be about 130 years.—*F. E.*

(a) In compliment to his patron, King George III. Mr. *Herſchel* named his recently diſcovered planet *Georgium Sidus*. The republican *Condorcet*, in contempt of Kings, gives it the name of the Diſcoverer.—*E. E.*

LETTER LX.

The same Subject continued.

IN addition to what I have said respecting the solar system, I must communicate some observations for the explanation of the figures. And, first, it must be remarked, that the lines which mark the paths in which the planets move, have no real existence in the heavens, as the whole immensity of space in which they move is a vacuum, or rather filled with that subtile matter which we call the *ether*, and which I have already so often mentioned.

Again, the orbits of the planets are not all in the same plane, as the figure presents them: but if the orbit which the earth describes round the sun, is properly represented on the paper, we must imagine the orbits of the five other planets to be partly elevated, and partly depressed, with reference to it; or, that the orbit of each planet bears upon it an oblique direction, making an intersection with the paper, under a certain angle, which it is impossible to represent in a figure drawn upon a plane.

Farther, the orbits of the planets are not circles, as the figure appears to indicate, but rather somewhat oval, one more, another less so; no one, however, recedes very considerably from the circular form. The orbit of Venus is almost a perfect circle; but those of the other planets are more or less extended

tended lengthwife, fo that thefe planets are fometimes nearer to the fun, fometimes farther off.

The orbits of comets are particularly diftinguifhable, being greatly extended in length, as I have reprefented it in the figure. As to the moon, and the fatellites of Jupiter and Saturn, their orbits, too, are nearly circular.

Neither muft we conceive them as moving in one and the fame direction, as they appear on the plane of the paper; for they do not remain in the fame place, but are themfelves carried round the fun along with the primary planet to which they belong. It is thus we muft underftand the lines reprefented in the figure. Imagination muft fupply what it is impoffible, on a plane furface, accurately to exhibit.

You are now enabled to comprehend, with eafe, what the late Mr. *de Fontenelle* meant to difplay, in his book on the plurality of worlds. The earth, with it's inhabitants, is fometimes denominated a world; and every planet, nay, every one of the fatellites, has an equal right to the fame appellation, it being highly probable, that each of thefe bodies is inhabited as well as the earth.

There are fixteen worlds, then, in the folar fyftem alone. And every fixed ftar being a fun, round which a certain number of planets perform their revolutions, and of which fome have, undoubtedly, their fatellites, we have an almoft infinite number of worlds, fimilar to our earth, confidering, that the number of ftars, perceptible to the unaffifted eye, exceeds ſome thouſands, and that the teleſcope diſcovers to us an incomparably greater number?

If it is meant to comprehend under the name of *world* the ſun, with the planets and their ſatellites, and which derive heat and light from him, we ſhall have as many worlds as there are fixed ſtars. But if by the term *world*, we underſtand the earth, with all the heavenly bodies, or all the beings which were created at once, it is clear that there can be but one world, to which we refer every thing that exiſts. It is in this ſenſe the term *world* is employed in philoſophy, particularly in metaphyſics; it is in this ſenſe we ſay, that there is but one world, the aſſemblage of all created beings, paſt, as well as preſent, and future, whoſe exiſtence is ſubject to general laws.

When, therefore, philoſophers diſpute, whether our world is the beſt or not, they proceed on the ſuppoſition of a plurality of worlds; and ſome maintain, that the one which exiſts, is the beſt of all thoſe which could have exiſted. They conſider the Deity as an architect, who, intending to create this world, traced ſeveral different plans, of which he ſelected the beſt, or that in which the greateſt perfections were all combined, in the higheſt degree, and executed it in preference to all the others.

But the great quantity of evil that prevails, and is diffuſed over the ſurface of our globe, and which flows from the wickedneſs of man, ſuggeſts an important enquiry, namely, Whether it would have been poſſible to create a world, wholly exempted from theſe evils?

In my opinion, a diſtinction muſt be carefully made, between the plans of a world, which ſhould contain corporeal ſubſtances only, and thoſe of another world, which ſhould contain beings intelligent and free. In the former caſe, the choice of the beſt, would be involved in very little difficulty; but in the other, where beings intelligent and free conſtitute the principal part of the world, the determination of what is beſt is infinitely beyond our capacity; and even the wickedneſs of free agents may contribute to the perfection of the world in a manner which we are unable to comprehend.

It would appear, that philoſophers have not been ſufficiently attentive to this diſtinction, however eſſential it may be. But I am too ſenſible of my own incapacity, to enter any deeper into this difficult queſtion.

19th September, 1760.

LETTER LXI.

Small Irregularities in the Motions of the Planets, cauſed by their mutual Attraction.

IN order to determine the motion of the bodies which compoſe the ſolar ſyſtem, it is neceſſary to diſtinguiſh the primary planets, which are Mercury, Venus, the Earth, Mars, Jupiter, and Saturn, from their ſatellites, namely, the moon, the four ſatellites of Jupiter, and the five of Saturn.

It

It has been explained to you, that these six planets are principally attracted toward the sun, or, that the force with which they are impelled toward him, is incomparably greater, than the powers which they exert one upon another, because his mass is incomparably greater than that of the planets, and because they never sufficiently approach to each other to render their reciprocal attraction very considerable. Were they attracted only toward the sun, their motion would be sufficiently regular, and easily determined. But the feebler powers of which I have been speaking, occasion some slight irregularities in their motion, which astronomers are eager to discover, and which geometricians endeavour to determine, on the principles of motion.

An important question is here agitated, namely, *The powers which act upon a body being known, how to find the motion of that body?* Now, upon the principles above laid down, we are acquainted with the powers, to the influence of which every planet is subjected. Thus the motion of the earth is somewhat affected; first, by the attraction of Venus, which sometimes passes very near it; and, secondly, by that of Jupiter, which, on account of the prodigious mass of this planet, becomes considerable, though he be always at a great distance. The mass of Mars is too small to produce any perceptible effect, though he is sometimes very near us; and Saturn, though his mass be the greatest, next to that of Jupiter, is too distant.

The moon, though her mass be very small, produces,

duces, however, ſome derangement, from her being very near the earth. The comet, which appeared laſt year, was ſeven times nearer to us than the ſun, when his diſtance was ſmalleſt; there is a great degree of probability, therefore, that it may have deranged the earth's motion, eſpecially if his maſs was conſiderable, a circumſtance with which we are not acquainted. If this comet were as great as the earth, the effect muſt have been very conſiderable; but it's apparent ſmallneſs induces me to believe, that it's maſs is much leſs than that of the earth, and, conſequently, it's effect muſt have been proportionally leſs. When we ſaw this comet, however, it had got to a great diſtance; at the time when it was neareſt, it was inviſible to us, but it muſt have appeared very brilliant to our antipodes.

What has been ſaid, reſpecting the derangements occaſioned in the earth's motion, takes place likewiſe in the other planets, regard being had to their maſs, and to their proximity. As to the moon, and the other ſecondary planets, the principle of their motion is ſomewhat different. The moon is ſo near the earth, that the attraction ſhe feels from hence greatly exceeds that of the ſun, though the maſs of this luminary be many thouſands of times greater than that of the earth. Hence it is, that the motion of the moon follows that of the earth, and that ſhe remains, as it were, attached to it, which makes the moon to be conſidered as a ſatellite to our planet.

Had the moon been placed much farther from us, and had ſhe been attracted leſs toward the earth than

toward

toward the ſun, ſhe would have become a primary planet, and performed her own revolutions round the ſun; but ſhe is 300 times nearer to us than ſhe is to the ſun; hence it is evident, that he muſt exercise a much feebler influence upon her than the earth does. The moon being principally attracted by two bodies, the ſun and the earth, it is evident that the determination of her motion, muſt be much more difficult than that of the primary planets, which are ſubject to the attraction of the ſun only, excepting the ſlight derangements which have been mentioned. The motion of the moon has, accordingly, in all ages, greatly embarraſſed philoſophers; and never have they been able to aſcertain, for any future given time, the exact place of the moon in the heavens.

You perfectly comprehend, that in order to predict an eclipſe, whether of the moon or of the ſun, we muſt be able accurately to aſcertain the moon's place. Now, in calculating eclipſes, formerly, there was frequently a miſtake of an hour or more: the eclipſe actually taking place an hour earlier or later than the calculation. Whatever pains the ancient aſtronomers took to determine the moon's motion, they were always very wide of the truth. It was not till the great *Newton* diſcovered the real powers which act upon the moon, that we began to approach nearer and nearer to truth, after having ſurmounted many obſtacles which retarded our progreſs.

I too have employed much time and attention on the ſubject; and Mr. *Meyer*, of Gottingen, purſuing

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the track which I had opened, has arrived at a degree of precifion, beyond which it is perhaps impoffible to go. Not much more, then, than ten years have elapfed fince we could boaft of any thing like accurate knowledge of the moon's motion. Since that time we are able to calculate eclipfes fo exactly, as not to make the miftake of a fingle minute, whereas, before, there was frequently the difference of eight minutes, and more. To analyfis, then, we are indebted for this important difcovery, the fource of unfpeakable advantages, not to the aftronomer only, but likewife to the geographer, and the navigator.

23d September, 1760.

LETTER LXII.

Defcription of the Flux and Reflux of the Sea.

THE attractive power of the heavenly bodies extends, not only to the mafs of the earth, but to all the parts of which it is compofed. Thus all the bodies, which we fee on the furface of the earth, are attracted, not only toward the earth itfelf, from which refults their gravity, and the weight of every one in particular, but, likewife, toward the fun, and toward all the other heavenly bodies, and that more or lefs, according to the mafs of thefe bodies and their diftance.

Now, it is evident, that the force with which a body,

body, ſay a ſtone, is attracted toward the earth, muſt be incomparably greater than that with which the ſame body is attracted toward the ſun, the other planets, and the moon, becauſe of their great diſtance. Such a body, being at a diſtance from the centre of the earth, equal to a radius of this globe, is 60 times farther from the moon. Though, then, the maſs of the moon were equal to that of the earth, the attraction toward the moon would be 60 times 60, that is 3600 times leſs than the attraction toward the earth, or, the gravity of the body. But, the maſs of the moon is about 70 times leſs than that of the earth; hence the attractive power of the moon becomes ſtill 70 times 3600, that is, 252,000 times leſs than the gravity of the body.

Again, though the ſun be many thouſands of times greater than the earth, he is about 24,000 times more diſtant from us, than the centre of the earth; and for this reaſon, the attraction of the ſun upon a ſtone is extremely ſmall, compared to it's gravity. Hence you ſee, that the gravity of terreſtrial bodies, which is nothing elſe but the force with which they are attracted toward the earth, cannot be perceptibly affected by the attraction of the heavenly bodies.

Though this attraction, however, be very inconſiderable, there reſults from it a remarkable phenomenon, which long puzzled philoſophers; I mean the flux and the reflux of the ſea. It occurs ſo frequently, even in common converſation, that it is almoſt a matter of neceſſity to underſtand it. For this reaſon, I propoſe to explain more minutely, this ſingular

gular phenomenon, and to unfold the causes which produce it.

I begin, then, with the description of the well-known phenomenon, of the *flux* and *reflux* of the sea. Hardly any one is ignorant, that by far the greatest part of the surface of our globle is covered with a mass of water, called the *Sea*, or the *Ocean*. This immense fluid mass is very different from rivers and lakes, which, according to the different seasons of the year, contain sometimes less water, sometimes more, whereas, in the sea, the quantity of water, at all times, continues nearly the same. It is, however, observed, that the water of the sea rises and falls alternately, with wonderful regularity, twice every twenty-four hours.

If, for instance, in a harbour, the water is now at it's greatest height, it will presently begin to subside, and this decrease continues for six hours, at the end of which, it's depth will be at the lowest. It then begins again to rise, and the increase, likewise, lasts six hours, when it is again at it's greatest depth. It immediately begins again to fall for six hours, and then rises as many, so that in the space of about 24 hours, the water rises and falls twice; and arrives, alternately, at it's greatest and least depth.

It is this alternate increase, and diminution of the water of the sea, which we call it's *flux* and *reflux*, or it's flowing and ebbing: and more particularly, the flux denotes the time, during which it encreases or rises, and the reflux, the time of it's decrease or falling. The flux and reflux together, likewise, go by the

the name of *tide*. This alternation, then, is to be the ſubject of our preſent diſquiſition.

It is, firſt of all, to be remarked, that the difference between riſing and falling, keeps pace with the variations of the moon. At full, and new moon, the water riſes higher than at the quarters: and about the time of the vernal, and autumnal equinoxes, in the months of March and September, this alternate motion of the ſea is moſt conſiderable. A great difference is, likewiſe, obſerved, according to the ſituation of the coaſts. The flux, in ſome places, is never more than a few feet, while, in others, the riſe is 40 feet and upwards. Such are the tides in the ports of St. *Malo*, in France, and of *Briſtol*, in England.

It is farther to be remarked, that this phenomenon is perceptible, chiefly, in the ocean, where there is a vaſt extent of water, and that in ſeas bounded and confined, ſuch as the Baltic, and the Mediterranean, it is much leſs conſiderable. The interval, from the flux to the ſucceeding reflux, is not exactly ſix hours, but about 11 minutes more; ſo that the ſame changes do not take place, the day after, at the ſame hour, but fall out about three quarters of an hour later: ſo that a revolution of 30 days is requiſite, to bring them round to the ſame hour; now, this is preciſely the period of one revolution of the moon, or the interval, between one new moon, and that which immediately follows.

26th September, 1760.

LETTER

LETTER LXIII.

Different Opinions of Philoſophers reſpecting the Flux and Reflux of the Sea.

WHEN the water of the ſea riſes at any place, we are not to imagine that it ſwells from any internal cauſe, as milk does when put in a veſſel upon the fire. The elevation of the ſea is produced by a real increaſe of water flowing hither from ſome other place. It is a real current which is very perceptible at ſea, conveying the waters toward the place where the flux is.

In order to have a clearer comprehenſion of this, you muſt conſider that in the vaſt extent of the ocean there are always places where the water is low, while it is high at others; and that it is conveyed from the former to the latter. When the water riſes at any place, there is always a current, conveying it from other places, where it is of courſe at that time low. It is an error, therefore, to imagine, with ſome authors, that during the flux of the ſea the total maſs of water becomes greater, and that it diminiſhes during the reflux. The entire maſs or bulk of water remains ever the ſame; but it is ſubject to a perpetual oſcillation, by which the water is alternately tranſported from certain regions to others; and when the water is high at any place, it is of courſe low ſomewhere elſe, ſo that the increaſe at places where it is high is precifely equal to the decreafe at thofe where it is low.

Such are the phenomena of the flux and reflux of the fea, the caufe of which ancient philofophers endeavoured to difcover, but in vain. *Kepler*, in other refpects a great aftronomer, and the ornament of Germany, believed that the earth, as well as all the heavenly bodies, was a real living animal, and confidered the flux and reflux of the fea as the effect of it's refpiration. According to this philofopher, men and beafts were juft like infects feeding on the back of the huge animal. You will hardly expect I fhould go into the refutation of an opinion fo ridiculous.

Defcartes, that great French philofopher, endeavoured to introduce a more rational philofophy; and remarked, that the flux and reflux of the fea was principally regulated by the moon's motion; which was indeed a very important difcovery, though the ancients had already fufpected a connection between thefe two phenomena. For if high water or the top of the flux happen to-day at noon, it will be low water at 11 minutes after fix in the evening: it will rife till 22 minutes after midnight; and the next low water will be 33 minutes after fix in the morning of the day after; and the enfuing high water, or flux, will be three quarters of an hour after noon: fo that from one day to another the fame tides are later by three quarters of an hour.

And as the fame thing precifely takes place in the moon's motion, which rifes always three quarters of

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an hour later than the preceding day, it was presumable that the tides followed the courfe of the moon. If at any given place, for example, on the day of new moon, high water happen to be at three of the clock, afternoon, you could reft affured, that ever after, on the firft day of the moon, the flux would invariably be at the height at three o'clock afternoon, and that every following day it would fall later by three quarters of an hour.

Again, not only the time when every flux and reflux happen exactly follows the moon, but the ftrength of the tides, which is variable, appears ftill to depend on the pofition of the moon. They are every where ftronger after the new and full moon, that is, at thefe periods the elevation of the water is greater than at other times; and after the firft and laft quarters, the elevation of the water, during the flux, is fmaller. This wonderful harmony between the tides, and the motion of the moon, was, undoubtedly, fufficient ground to conclude, that the chief caufe of the flux and reflux of the fea was to be fought for in the action of the moon.

Defcartes accordingly believed, that the moon, in paffing over us, preffed the atmofphere, or the air which furrounds the earth, and that the air preffing on the water, in it's turn, forced it to fubfide. Had this been the cafe, the water muft have been depreffed at the places over which the moon was, and that the fame effect fhould be produced 12 hours after, in the enfuing tide; which, however, does not happen. Befides the moon is too diftant from the earth, and the atmoſphere too low to be impreſſed by the moon; and admitting that the moon, or any other great body, were to paſs along the atmoſphere, it would be very far from undergoing any preſſure from it, and ſtill leſs would the ſea feel this pretended preſſure.

This attempt of *Deſcartes* to explain the flux and reflux of the ſea, has therefore failed; but the connection of this phenomenon with the moon's motion, which this philoſopher has ſo clearly unfolded, enabled his ſucceſſors to employ the application of their reſearches with more ſucceſs. This ſhall be the ſubject of ſome following letters.

30th September, 1760.

LETTER LXIV.

Explanation of the Flux and Reflux, from the attractive Power of the Moon.

DESCARTES's method of explaining the flux and reflux of the ſea, by the preſſure of the moon upon our atmoſphere, not having ſucceeded, it was reaſonable to look for the cauſe of it in the attraction which the moon exerciſes upon the earth, and conſequently alſo upon the ſea.

The attractive power of the heavenly bodies having been already ſufficiently eſtabliſhed, by ſo many other phenomena, as I have ſhewn, it could not be doubted that the flux and reflux of the ſea muſt be an an effect of it. As ſoon as it is demonſtrated that the moon, as well as the other heavenly bodies, is endowed with the property of attracting all bodies, in the direct ratio of their maſs, and in the inverſe ratio of the ſquare of their diſtance, it is eaſily comprehended that it's action muſt extend to the ſea; and the more ſo, as you muſt frequently have obſerved, that the ſmalleſt force is capable of agitating a fluid. All that remains, therefore, is to enquire, whether the attractive power of the moon, ſuch as we ſuppoſe it, is capable of producing in the ſea the agitation known to us by the name of flux and reflux.

Let the annexed figure (*plate* III. *fig.* 5.) repreſent the earth and the moon. A is the place where we ſee the moon over the earth; B that which is directly oppoſite, or the antipodes of A; and C is the centre of the earth. As the point A is nearer the moon than the point B, a body at A is more powerfully attracted toward the moon than a ſimilar body at B. And if we ſuppoſe a third ſimilar body to be placed at the centre of the earth C, it is evident that the body A will be more powerfully attracted toward the moon than the body C, and this laſt than the body B, becauſe the body A is nearer to the moon, and the body B more remote than the body C. But ſimilar bodies placed at E and F, are almoſt as much attracted by the moon as that which is at the centre of the earth C, as they are all three nearly equi-diſtant from the moon.

Hence we ſee that bodies placed on the ſurface of the earth are not all equally attracted toward the moon. This inequality of attraction depends on the inequality of their diſtance from the centre of the moon L, ſo that a body is ſo much the more powerfully attracted by the moon, as it's diſtance is leſs; and the contrary takes place according as the diſtance is greater.

To theſe differences in the action of the moon on bodies differently ſituated, we muſt here chiefly pay attention; for if all bodies were equally attracted toward the moon, they would equally obey this power, and no derangement could take place in their mutual ſituation.

You can eaſily form the idea of ſeveral carriages drawn along by powers perfectly equal; they will proceed on the road, always preſerving the ſame order, and the ſame diſtances; but as ſoon as ſome of them advance more briſkly, and others more ſlowly, the order will be deranged. The ſame thing takes place in the caſe of the different bodies which are attracted by the moon; if they all felt, in the ſame degree, the action of that luminary, they would preſerve the ſame relative ſituation, and we ſhould perceive no change in them: but as ſoon as the force with which they are attracted toward the moon varies as to each of them, their order and their relative ſituation neceſſarily change, unleſs they are attached to each other by bands which that power is unable to burſt aſunder.

But this is not the caſe with the ſea, as all the particles of a fluid are eaſily ſeparated from each other, and

and every one may obey the impreffions which it receives. It is evident, then, that when the powers which act on the different parts of the fea are not equal to one another, an agitation, or derangement, muft be the confequence.

We have juft feen that the different parts of the fea are attracted unequally by the moon, according as they are unequally diftant from her centre; the fea muft, therefore, be agitated by the force of the moon, which, continually changing her fituation, with refpect to the earth, and performing a revolution round it in about twenty-four hours and three quarters, makes the fea undergo the fame changes, and prefents the fame phenomena in the fame period of twenty-four hours and three quarters; the flux and reflux muft, therefore, be retarded from one day to another three quarters of an hour, which is confirmed by conftant experience.

It now remains that we fhew, How the alternate elevation and depreffion of the fea, which fucceed each other after an interval of fix hours and eleven minutes, refult from the inequality of the powers of the moon. This I propofe to examine in my next letter.

4th October, 1760.

LETTER LXV.

The ſame Subject continued.

YOU have ſeen that the moon cauſes no alteration in the ſtate of the earth, but in ſo far as ſhe acts unequally on it's different parts. The reaſon of it is, that if all it's parts equally felt the ſame action, they would be equally attracted, and no change in their relative ſituation would reſult from it.

But a body being at A (*plate* III. *fig.* 5.) nearer the moon than the centre of the earth C, is more powerfully attracted to it than a body at C would be: it will approach it, then, with greater velocity than this laſt: from hence it neceſſarily follows, that the body A retires from the centre C, and approaches the moon: as if there were two chariots, the one at A, the other at C, and if the chariot A were drawn toward L with greater force than the chariot C, it would remove from C. It is thus that the power of the moon has a tendency to withdraw the point A from the centre C.

Now to remove a body from the centre of the earth is to raiſe it: and the water at A being now the thing in queſtion, it is certain that the force of the moon tends to raiſe the water which is at A, by a power equal to the exceſs of the attraction toward the moon felt at A, above that felt at C. By this power, then, the moon raiſes the waters of the earth which are immediately under her.

Let

Let us now, likewife, attend to a body at B, directly oppofite to the point A; the centre of the earth C, more powerfully attracted by the moon than the point B, will approach nearer to it, and this laft, fo to fpeak, will remain behind, juft as a chariot, which was drawn more flowly than that which precedes it. The point B will confequently remove from the centre C, and rife; for to remove from the centre of the earth, and to rife, is one and the fame thing.

It is evident, therefore, that the power of the moon tends to raife the waters, not only at A, but likewife at B, the point diametrically oppofite, and that by a force equal to the difference of the attraction of the moon at B and at C, which is lefs at B than at C. Now, thofe who are at A, have the moon directly above them, or in their zenith; and thofe who are at B fee nothing of the moon, becaufe fhe is then in a point of the heavens diametrically oppofite to their zenith, called *Nadir*.

Hence it appears, that at whatever part of the fea it may be, the water muft rife equally when the moon is in the zenith of that place, and in it's nadir, or, when the moon is at it's greateft elevation above the horizon, or at it's greateft depreffion under it. At the intermediate periods, when the moon is in the horizon, either rifing or fetting, fhe exercifes no power capable of raifing the fea; a fmall contrary power tends even to make it fall.

According to this fyftem, at the place of the fea, where the moon is in the zenith, it's power has a tendency

tendency to raiſe the waters; about ſix hours after, when ſhe has reached the horizon, her power has a tendency to make them fall. Twelve hours and twenty-two minutes after, the moon being then at the point moſt diſtant, under the horizon, ſhe exerciſes the ſame power to raiſe the water; and at the end of eighteen hours, thirty-three minutes, when ſhe has got to the oppoſite horizon, the waters are fallen: till at length, twenty-four hours and forty-five minutes from the firſt period, ſhe returns to the zenith, raiſing the water as on the preceding day: and this is confirmed by uniform experience.

This alternate elevation and depreſſion of the ſea, at intervals of ſix hours and eleven minutes, having ſuch a perfect conformity with the moon, leaves us no room to doubt that the flux and reflux of the ſea are cauſed by the attractive power of the moon.

It is a remarkable circumſtance that ſhe acts equally on the ſea, in raiſing it, whether ſhe is at her greateſt height above the horizon, or at the moſt diſtant point under it. This appeared at firſt very ſtrange to philoſophers, who imagined that the moon muſt produce, under the horizon, an effect contrary to that which ſhe produces when in the zenith. But you ſee clearly that the moon produces the ſame effect in theſe two diametrically oppoſite poſitions, as I have demonſtrated in the figure above referred to, that the effect of the moon is the ſame at A and at B.

7th October, 1760.

LETTER LXVI.

The ſame Subject continued.

FROM what has been ſaid reſpecting the flux and reflux of the ſea, you muſt be ſenſible that the ſyſtem of *Newton*, which I have adopted, is directly contrary to that of *Deſcartes*. According to this laſt, the moon exerciſes a preſſure, and the ſea muſt ſubſide at places ſituated directly under her; but, according to *Newton*, ſhe acts by attraction, and forces the water to riſe at theſe very places.

Experience, then, muſt determine which of theſe two ſyſtems is to be received. No more is neceſſary than to conſult the obſervations made with reſpect to the ocean, in order to ſee whether the water riſes or falls when the moon is in the zenith. Recourſe has actually been had to this; but it is found that when the moon is at either the zenith, or nadir, of a given place, the water there is neither high nor low; and that high water does not take place till ſome hours after the moon has paſſed the zenith.

From this circumſtance, perſons who examine things ſuperficially, concluded at once, that neither of the ſyſtems was admiſſible; and the Carteſians have taken advantage from it, preſuming, that if *Newton's* was rejected, that of *Deſcartes* muſt neceſſarily be adopted, though the obſervations referred to are as contrary to the ſyſtem of *Deſcartes* as they appear to be to that of *Newton*.

But

But the ſyſtem of *Deſcartes* is overturned by this ſingle phenomenon, that the ſea is always in the ſame ſtate after a period of twelve hours and twenty-two minutes, or that it's ſtate is always the ſame, whether the moon be above or below the horizon; and it is impoſſible for it's ſupporters to ſhew how the moon, being over the heads of our antipodes, can produce the ſame effect as when ſhe is over ours. To this purpoſe, ſee *plate* III. *fig.* 6.

Experience proves that the ſtate of the water at A is the ſame, whether the moon be at M, the zenith of the point A, or at N, it's nadir, which is conſequently the zenith of the antipodes at B. The effect, of the moon, then, on the water at A, is the ſame in both caſes. But if the moon acted by preſſure, according to *Deſcartes*, it would follow, that when the moon is at M, the water at A muſt fall; and if ſhe were at N, it is impoſſible that the water at A ſhould undergo the ſame preſſure.

In the ſyſtem of attraction, on the contrary, it is inconteſtably certain, that the action of the moon muſt be nearly the ſame, whether that luminary be at M or at N; and this is demonſtrated by actual obſervation.

I muſt here repeat a preceding explanation, becauſe it is a matter of the utmoſt importance. When the moon is at M, the point A is nearer it than the centre C; it is, therefore, more powerfully attracted than the centre; the point A will remove from the centre, conſequently it will then riſe: the moon being at M, has a tendency to raiſe the water at A.

Let

Let us now ſee what effect the moon, being at N, will produce, where ſhe arrives in twelve hours and twenty-two minutes after ſhe was at M. As the point A is more diſtant from the moon at N than the centre C, it will be more feebly attracted; the centre C will advance with greater velocity toward N, than the point A; the diſtance A C will accordingly become greater; the point A will, therefore, be more diſtant from the centre C. But to be more diſtant from the centre of the earth is to riſe, conſequently the moon being at N, makes the point A to aſcend, that is, ſhe has a tendency to raiſe the water at A, as if the moon were at M.

But here experience preſents a very formidable objection; for it is obſerved, that the moon being at M, or at N, the water is not then at it's greateſt elevation at A. This does not take place till a conſiderable time after, and thence ſome have been induced to reject this explanation altogether. But you will eaſily ſee that their deciſion is extremely precipitate.

I have not ſaid, that when the moon is at M or N, the water at A is at it's greateſt height; I have only ſaid, that the power of the moon has then a tendency to make the water riſe. But the water at A could not riſe, unleſs it's quantity were increaſed; and that increaſe can be produced only by the flowing of the water from other parts, ſome of them very diſtant. A conſiderable time, therefore, is requiſite to the accumulation of a ſufficient quantity of water; it is, then, very natural to ſuppoſe, that high water at A ſhould not take place for ſome time after the moon

has

has paſſed M or N. This obſervation, therefore, is ſo far from overturning our ſyſtem, that it tends ſtrongly to confirm it.

There is no room to doubt that the power which has a tendency to raiſe the ſea, muſt precede it's greateſt elevation, nay, that a conſiderable time muſt intervene, as the water muſt flow thither from places very remote, that is, from places where the water muſt be low, while it is high at A. If the water has to paſs through ſtraights, or has it's current otherwiſe obſtructed, high water will be ſtill more retarded;* and if, in the ocean, it is high water at A, two hours after the moon has paſſed M or N, it will not be at the height, in narrow and bounded ſeas, for three hours or more: and this perfectly agrees with daily obſervation.

11th October, 1760.

* It may be proper, in this place, to give a popular view of ſo intereſting a ſubject as that of tides. Suppoſe, therefore a ciſtern of water communicates with another, alſo of water, and in the ſame ſtate; the ſurface of both will conſtantly preſerve, or endeavour to preſerve, the ſame level. But if one of the ciſterns were filled with oil, or any ſuch light fluid, the ſurface would evidently riſe above the level of the other; and the more ſo, the greater was the depth of the oil. The ſame conſequence would follow, if, by any cauſe, the ſpecific gravity of the water in one of the ciſterns was diminiſhed. And this is actually the effect which the moon and ſun produce on the waters of the ocean; thoſe particles neareſt theſe luminaries are more attracted by them than the particles at the centre, or at the extremities of the tranſverſe diameter, which are more attracted than the particles on the fartheſt ſide; and therefore, in both caſes, the tendency to the centre is diminiſhed. Hence a protuberance will be formed on the nearer and farther

ſides

LETTER LXVII.

The ſame Subject continued.

IT is no longer, then, a matter of doubt, that the flux and reflux of the ſea is cauſed by the attractive power of the moon. But there remains one difficulty more to be removed: Why is the motion of the ſea much more conſiderable at the time of new and full moon than at the other quarters? If the moon were nearer the earth when ſhe is new, or full, than when ſhe is in her quarters, there would be no difficulty in the queſtion, as her proximity would increaſe her power. But though the moon approaches the earth ſometimes more, ſometimes leſs,

ſides of the globe, proportional to the depth of the ocean. But this general ſwell is never ſuffered to attain it's juſt elevation; for the neceſſary motions are not ſupported a ſufficient length of time, and the impreſſions ſoon give a contrary tendency. The flow of the waters is moſt obſtructed in narrow ſeas, which are remote from the great ocean. Hence the lateneſs and irregularity of the tides in ſuch ſeas. When a large river, or an arm of a ſea, frequently contracts and widens, it often happens that the tide, in puſhing up, occaſions a great ſwell in the narrows, which produces a ſtrong current, that continuing, after it's cauſe has ceaſed to operate, reduces the water below it's proper level, till a quantity is again accumulated, and repeats the ſame effects; and thus an ebb and flow may happen ſeveral times in the courſe of a day. This is particularly remarked in the river St. Lawrence, in North America.

A large lake cannot have any ſenſible tides, for every portion of it's waters is almoſt equally attracted by the ſun or moon.

the

the difference is always too ſmall to occaſion a change ſo conſiderable in the flux and reflux of the ſea.

Beſides, this difference is not regulated by the new and full moon; and it may happen, that the moon, in the intermediate quarters, ſhould be nearer to us than when ſhe is new or full. We muſt have recourſe, therefore, to another cauſe capable of increaſing the flux and reflux of the ſea at the new and full moon, and of diminiſhing it at the intermediate quarters.

The ſyſtem of attraction ſhews us, at firſt, that it is the action of the ſun which, joined to that of the moon, furniſhes a complete ſolution of all the phenomena preſented to us by the flux and reflux of the ſea. Indeed, all that I have ſaid reſpecting the power which the moon exerciſes on the ſea, is equally applicable to the ſun, whoſe attractive power acts likewiſe unequally on all the parts of the earth, according as they are more or leſs remote from him. The attraction of the ſun is even much more intenſe than that of the moon, as it chiefly regulates the motion of the earth, and carries it round it's orbit.

As to the motion which he communicates to the ſea, it depends on the inequality of that action, with relation to the different points of the ſurface of the earth, which are more or leſs attracted toward the ſun than it's centre, as I have already ſhewed you, in explaining the effect of the moon. If all the parts of the earth were attracted equally, no change in their mutual ſituation would take place. But though the power of the ſun be much greater than that of the

the moon, the inequality, with relation to different parts of the earth is, neverthelefs, fmaller, on account of the great diftance of the fun, which is 300 times farther from us than the moon. The difference of the power with which the centre of the earth, and the points of it's furface, are attracted toward the fun, is, therefore, very fmall; and from calculations actually made, it is found to be three times lefs, nearly, than that of the moon upon thefe points. The attractive power of the fun alone, then, would likewife be capable of caufing the flux and reflux of the fea; but it would be about three times lefs than that which is the effect of the combined influence of thefe two luminaries.

It is evident, then, that the flux and reflux of the fea are produced by the power of both the fun and the moon, or that there are really two tides, occafioned, the one by the moon, the other by the fun, and called the *lunar tide* and the *folar tide*. That of the moon, nearly three times greater, follows it's motion, and from one day to another is retarded three quarters of an hour: that which follows the action of the fun, would conftantly correfpond to the fame hours of the day, if it exifted alone, or if there were no moon. Thefe two tides, the lunar and the folar together, produce the flux and reflux of the fea; but as the one and the other, feparately, make the waters of the fea alternately to rife and fall, when it happens that thefe two caufes, conjointly, make the fea rife and fall, it's flux and reflux become much more confiderable; but when the one tends to raife the ſea, and the other to lower it, at the ſame place, when they act in contrary directions, the one will then be diminiſhed by the other, and the lunar tide will be weakened by the ſolar. According as theſe two tides aſſiſt, or check, each other, the flux and reflux will, then, be more or leſs conſiderable.

Now, as at the time of new moon, the ſun and moon are in the ſame parts of the heavens, their effects being perfectly in uniſon, the flux and reflux muſt then be greateſt, being equal to the ſum of the two tides. This will equally take place at the time of full moon, when the moon is oppoſite to the ſun, as we know that ſhe produces the ſame effect, though ſhe be in a point of the heavens diametrically oppoſite to the firſt. The flux and reflux muſt, therefore, be greater at new and full moon, than at the firſt and laſt quarters. For then the power of the ſun is exerted to lower the waters, and that of the moon to raiſe them. It is evident, therefore, that, at theſe ſeaſons, the flux and reflux muſt be leſs conſiderable, and actual obſervation confirms it.

It might be ſtill farther demonſtrated, by calculation, that the effect of the moon, or of the ſun, is ſomewhat greater, when theſe bodies are at the equator, or equally diſtant from the two poles of the globe: which happens at the time of the equinoxes, toward the end of the months of March and September. It is found, too, that then the tides are ſtrongeſt. It follows beyond all doubt, then, that the tides, or the flux and reflux of the ſea, are cauſed by the attractive power of the moon and of the ſun,

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in as much as theſe powers act unequally on the different parts of the ſea. The happy explanation of this phenomenon, which had ſo dreadfully perplexed the ancients, is a complete confirmation of the ſyſtem of attraction, or of univerſal gravitation, on which is founded the motion of all the heavenly bodies.

14th October, 1760.

LETTER LXVIII.

More particular Account of the Diſpute reſpecting univerſal Gravitation.

HAVING given you a general, but exact, idea of the powers which produce the principal phenomena of the univerſe, and on which are founded the motions of all the heavenly bodies, it is of importance to conſider, with more attention, thoſe powers which are the principal points of the ſyſtem of attraction.

It is ſuppoſed, in this ſyſtem, that all bodies mutually attract each other, in the ratio of their maſs, and relatively to their diſtance, in conformity to a law already explained. The ſatisfying manner in which moſt of the phenomena in nature are accounted for, proves that this ſuppoſition is founded in truth; and that the attraction which different bodies exerciſe upon each other, may be conſidered as a moſt undoubted fact. It now remains, that we enquire into the cauſe of theſe attractive powers; but this research belongs rather to the province of metaphyſics than of mathematics. I dare not, therefore, flatter myſelf with the proſpect of aſſured ſucceſs in the proſecution of it.

It being certain, that any two bodies whatever are attracted to each other, the queſtion is, What is the cauſe of this attraction? On this point philoſophers are divided. The Engliſh maintain, that attraction is a property eſſential to all the bodies in nature, and that theſe bodies, hurried along by an irreſiſtible propenſity, tend mutually to approach, as if they were impelled by feeling.

Other philoſophers conſider this opinion as abſurd, and contrary to the principles of a rational philoſophy. They do not deny the fact; they even admit, that powers exiſt, which are the cauſes of the reciprocal tendency of bodies toward each other; but they maintain, that they are foreign to the bodies; that they belong to the ether, or the ſubtile matter which ſurrounds them, and that bodies may be put in motion by the ether, juſt as we ſee that a body, plunged into a fluid, receives ſeveral impreſſions from it. Thus, according to the firſt, the cauſe of the attraction reſides in the bodies themſelves, and is eſſential to their nature; and, according to the laſt, that it is out of the bodies, and in the fluid which ſurrounds them. In this caſe, the term attraction would be improper; and we muſt rather ſay, that bodies are impelled toward each other. But as the effect is the ſame, whether two bodies are reciprocally impelled, or attracted, the word attraction

tion need not give offence, provided it is not pretended, by that term, to determine the nature itſelf of the cauſe.

To avoid all confuſion which might reſult from this mode of expreſſion, it ought rather to be ſaid, that bodies move, as if they mutually attracted each other. This would not decide, whether the powers which act on bodies reſide in the bodies themſelves, or out of them; and this manner of ſpeaking might thus ſuit both parties. Let us confine ourſelves to the bodies which we meet with on the ſurface of the earth.

Every one readily admits, that all theſe would fall downward, unleſs they were ſupported. Now, the queſtion turns on the real cauſe of this fall. Some ſay, that it is the earth which attracts theſe bodies, by an inherent power natural to it; others, that it is the ether, or ſome other ſubtile or inviſible matter, which impels the body downward: ſo that the effect is, nevertheleſs, the ſame in both caſes. This laſt opinion is moſt ſatisfactory to thoſe who are fond of clear principles in philoſophy, as they do not ſee, how two bodies at a diſtance can act upon each other, if there be nothing between them. The others have recourſe to the divine Omnipotence, and maintain, that God has endowed all bodies with a power of mutual attraction.

Though it be dangerous to venture on diſputing concerning the limits of divine power, it is, nevertheleſs, certain, that if attraction were an immediate work of that power, without being founded in the nature of bodies, this would be the ſame thing as ſaying, that God immediately impels bodies toward each other, and this would amount to a perpetual miracle.

Let us ſuppoſe, that before the creation of the world, God had created only two bodies, at a diſtance from each other; that nothing abſolutely exiſted out of them, and that they were in a ſtate of reſt; would it be poſſible for the one to approach the other, or that they ſhould have a propenſity to approach? How could the one feel the other at a diſtance? Whence could ariſe the deſire of approaching?. Theſe are perplexing queſtions. But if you ſuppoſe that the intermediate ſpace is filled with a ſubtile matter, we can comprehend, at once, that this matter may act upon the bodies, by impelling them; the effect would be the ſame as if they poſſeſſed a power of mutual attraction.

Now, as we know, that the whole ſpace which ſeparates the heavenly bodies, is filled with a ſubtile matter, called *ether*, it ſeems more reaſonable to aſcribe the mutual attraction of bodies to an action the ether exerciſes upon them, though it's acting may be unknown to us, rather ecourſe to an unintelligible property. loſophers ſatisfied themſelves with ex- henomena of nature, from qualities ed *occult*, ſaying, for example, that ep, from an occult quality, which procure ſleep. This was ſaying juſt her was an attempt to conceal ignorance.

rance. We ought, therefore, likewife to confider attraction as an occult quality, in as far as it is given for a property effential to bodies. But, as the idea of all occult qualities is now banifhed from philofophy, attraction ought not to be confidered in this fenfe.

18th October, 1760.

LETTER LXIX.

Nature and Effence of Bodies: or Extenfion, Mobility, and Impenetrability of Body.

THE metaphyfical difquifition, Whether bodies may be endowed with an internal power of attracting each other, without being impelled by an external force, cannot be terminated, till we have examined more particularly the nature of body in general. As this fubject is of the laft importance, not only in mathematics and phyfics, but in every branch of philofophy, you muft permit me to go into a more particular detail of it.

Firft, it is afked, What is body? However abfurd this queftion may appear, as no one is ignorant of the difference between what is body and what is not, it is, however, difficult to afcertain the real characters which conftitute the nature of bodies. The Cartefians fay, it confifts in extenfion, and that whatever is extended is a body. They clearly underftand, that extenfion has, in this cafe, three dimenſions; and that a ſingle dimenſion, or extenſion in length only, gives only a line; and that two dimenſions, length and breadth, form only a ſurface, which ſtill is not a body. To conſtitute a body, therefore, we muſt have three dimenſions, and every body muſt have length, breadth, and depth, or thickneſs; in other words, an extenſion in three dimenſions.

But, it is aſked, at the ſame time, if every thing which has extenſion is a body? This muſt be the caſe, if the definition of *Deſcartes* be juſt. The idea which the vulgar form of ſpectres contains extenſion; it is, however, denied that they are bodies. Though this idea be purely imaginary, it ſerves to prove, however, that ſomething may have extenſion without being a body. Beſides, the idea which we have of ſpace, contains, undoubtedly, an extenſion with three dimenſions. It is admitted, nevertheleſs, that ſpace alone is not a body; it only furniſhes the place which bodies occupy and fill.

Let us ſuppoſe, that all thoſe which are at preſent in my apartment, air and every thing, were annihilated by the divine Omnipotence, there would remain ſtill in the apartment the ſame length, breadth and height, but without a body in it. Here, then, is the poſſibility of an extenſion that ſhall not be a ody. Such a ſpace, without body in it, is called a uum; a vacuum then is extenſion without body. t may likewiſe be ſaid, according to the vulgar perſtition, that a ſpectre has extenſion, but that dy, or corporality, is wanting to it. It is clear, en, that extenſion is not ſufficient to conſtitute a body,

body, that ſomething more is neceſſary; hence it follows, that the definition of the Carteſians is not exact. But what more is neceſſary, beſide extenſion, to conſtitute a body? The anſwer is, mobility, or the poſſibility of being put in motion; for, though a body be at reſt, whatever may be the cauſes which preſerve it in that ſtate, it would, however, be poſſible to move it, provided the powers applied to it were ſufficient. By this, ſpace is excluded from the claſs of bodies, as we ſee that ſpace, which only ſerves to receive bodies, remains immoveable, whatever motion the bodies that it contains may have.

It is likewiſe ſaid, that, by the help of motion, bodies are tranſported from one place to another; by which we are given to underſtand, that the places and ſpace remain unchangeable. My apartment, however, with the vacuum which I have above ſuppoſed, might undoubtedly be moved, and actually is ſo, as it follows the motion which carries round the earth itſelf; here, then, is a vacuum in motion, without being a body. The vulgar ſuperſtition, too, beſtows motion on ſpectres; and this is ſufficient to prove, that the power of being moved, and extenſion, alone, do not conſtitute the nature of bodies. Something more is wanting; there muſt be matter to conſtitute a body, or rather, it is this which diſtinguiſhes a real body from ſimple extenſion, or from a ſpectre.

Here, then, we are reduced to explain what is to be underſtood by the term *matter*, without which extenſion cannot be body. Now, the ſignification of of theſe two terms is ſo much the ſame, that all body is matter, and all matter is body; ſo that even now we have made no great progreſs. We eaſily diſcover, however, a general character, inſeparable from all matter, and, conſequently, pertaining to all bodies; it is *impenetrability*, the impoſſibility of being penetrated by other bodies, or the impoſſibility that two bodies ſhould occupy the ſame place at once. In truth, impenetrability is what a vacuum wants in order to be a body.

It will, perhaps, be objected, that the hand may be eaſily moved through air and through water, which are, nevertheleſs, acknowledged bodies; theſe, then, muſt be penetrable bodies, and, conſequently, impenetrability is not an inherent character of all bodies. But it is worthy of remark, that when you plunge your hand into water, the particles of the water make way for your hand, and that there is no water in the ſpace which your hand occupies. If the hand could move through the water, while that fluid did not make room for it, but remained in the place which the hand occupied, then it would be penetrable; but it is evident this is not the caſe. Bodies, then, are impenetrable: a body, therefore, always excludes, the place which it occupies, every other body; as ſoon as a body enters into any place, it is aby neceſſary that the body which occupied it ſhould leave it. This is the ſenſe which we fix to the term impenetrability.

October, 1760.

LETTER

LETTER LXX.

Impenetrability of Bodies.

THE inftance of a fpunge will, perhaps, be produced as an objection to the impenetrability of bodies; which, plunged into water, appears completely penetrated by it. But the particles of the fpunge are very far from being fo, in fuch manner as that one particle of the water fhould occupy the fame place with one particle of the fpunge. We know that fpunge is a very porous body; and that before it is put into the water, it's pores are filled with air; as foon as the water enters into the pores of the fpunge, the air is expelled, and difengages itfelf under the form of little bubbles; fo that, in this cafe, no penetration takes place, neither of the air by the water, nor of the water by the air, as this laft always makes it's efcape from the places into which the water enters.

It is, then, a general, and effential property of all bodies, to be impenetrable; and, confequently, the juftnefs of this definition muft be admitted: *that a body is an impenetrable extenfion*; as not only all bodies are extended and impenetrable, but likewife, reciprocally, as that which is, at the fame time, extended and impenetrable, is, beyond contradiction, a body. Vacuum is, accordingly, excluded from the clafs of bodies; for, though it has extenfion, it wants impenetrability; and wherever we meet with a vacuum,

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there bodies may be introduced, without thrusting any thing out of it's place.

We must attempt to remove another difficulty, raised against the impenetrability of bodies. There are, say the objectors, bodies, which admit of compression into a smaller space, as, for example, wool, and especially air, which it is possible to reduce into a space a thousand times smaller than what it occupies. It appears, then, that the different particles of air are reduced in the same place, and that, consequently, they mutually penetrate.

There is, however, nothing in this; for the air, too, is a body, or a substance full of empty pores, or filled with that fluid, incomparably more subtile, which we call *ether*. In the first case, no penetration will ensue, as the particles of air only approach nearer to each other, according as the vacuum is diminished; and, in the other case, the ether finds a sufficiency of small passages by which to escape, as the particles of the air approach each other, but all the while without any mutual penetration. For this reason, it is necessary to employ a greater force, when we want to compress the air more: and if the air were compressed to such a degree, that it's minute particles touched each other, we could not carry the compression farther, because, were it possible, the minute particles of the air must mutually penetrate.

It is, then, a necessary and fundamental law in nature, that no two bodies can penetrate each other, or occupy the same place at once: and it is in a conformity to this principle, that we must look for the real

source

ſource of all the motions which we obſerve in all bodies, and of the changes which befal them. As two bodies cannot continue their motion without penetrating each other, it is abſolutely neceſſary that the one ſhould give place to the other. If, then, two bodies are moving in the ſame line, the one to the left, the other to the right, as it frequently happens at billiards, if each were to continue it's motion, they muſt mutually penetrate, but this being impoſſible, as ſoon as they come to touch, a ſhock takes place, by which the motion of each body is almoſt inſtantly changed; and this ſhock is produced, in nature, only to prevent penetration. The motion of each body is preciſely changed no further than is neceſſary to prevent all penetration; and in this conſiſts the real cauſe of all the changes which happen in the world.

When all theſe changes are attentively conſidered, they are found always to take place, in order to prevent ſome penetration, which, without theſe changes, muſt have enſued. At the moment I am writing, I obſerve, that if the paper were penetrable, the pen would paſs freely into it, without writing: but as the paper ſuſtains the preſſure of my pen, moiſtened with ink, it receives from it ſome particles which form theſe letters; which could not happen if bodies penetrated each other.

This property of all bodies, known by the term *impenetrability*, is, then, not only of the laſt importance, relatively to every branch of human knowledge, but we may conſider it as the maſter-ſpring which

which nature fets a-going, in order to produce all her wonders. It merits, then, an attentive examination, in order that we may be enabled to explain more clearly the nature of bodies, and the principles of every fpecies of movement, commonly called *laws of motion*.

25th October, 1760.

LETTER LXXI.

Of the Motion of the Bodies, real and apparent.

ALL bodies are at reft, or in motion. However evident this diftinction may be, it is almoft impoffible to judge whether a body is in the one ftate, or in the other. The paper which I fee on my table feems to me really at reft; but when I reflect that the whole earth is moving with that aftonifhing velocity which I explained in a former letter,* my houfe, my table, and the paper, muft abfolutely be carried along with the fame rapidity. Thus every thing that feems to be at reft, has, in reality, the fame motion as the earth.

'e muft therefore diftinguifh between two kinds , the one abfolute, the other apparent. Abfo- t takes place when a body remains conftantly fame place, not with relation to the earth, th relation to the univerfe. If the fixed ftars ed always in the fame place of the univerfe,

* Letter II.

they

they would be at reſt, though they ſeem to move very rapidly; but as we are not certain of it, we muſt not pretend to affirm, that the fixed ſtars are in a ſtate of abſolute reſt.

A body is ſaid to be in a ſtate of apparent reſt, when it preſerves the ſame ſituation on the earth. It is likewiſe to be preſumed, that theſe terms, reſt and motion, have been introduced into language to mark rather appearances than truth; and in this ſenſe, I affirm, without heſitation, that my table is at reſt, as well as the whole earth; and that the ſun and the fixed ſtars are in motion, and that a very rapid motion, although they are really at reſt. We ſhould, therefore, be aſcribing ſtrange and purely metaphyſical ideas to theſe expreſſions, if we underſtood by them *abſolute reſt*, or *motion;* and it is abſurd to employ, as ſome perſons do, paſſages of the Holy Scriptures to prove that the earth is at reſt, and the ſun in motion.

Language is formed for general uſe; and philoſophers are under the neceſſity of forming a particular language for themſelves. As we are incapable to judge of abſolute reſt, it is very natural for us to conſider thoſe bodies as at reſt which preſerve the ſame ſituation relatively to the earth; as it is very probable the inhabitants of other planets, likewiſe, form their judgment of reſt from the ſame ſituation relatively to their reſpective planet.

We obſerve, that navigators conſider as at reſt the objects which preſerve the ſame ſituation relatively to their veſſel, and that the coaſts which they diſcover appear to them to be in motion; and no one thinks of finding fault with their uſing the common modes of expreſſion. There is, therefore, a great difference between reſt and motion, real or abſolute, and between reſt and motion apparent, or relative to a body, conſidered at the time as in a ſtate of reſt, though perhaps it may be in motion. The principles or laws of motion refer chiefly to the abſolute ſtate of bodies, that is, to their reſt or motion, real or abſolute. In order to diſcover theſe laws, we begin with conſidering a body ſingly and abſtractedly from all others.

This hypotheſis, though it never can take place, is, in reality, very proper to aſſiſt us in diſtinguiſhing what is operated by the nature of body itſelf, from that which other bodies are capable of operating upon it.

Let a body, then, be alone, and at reſt; it may be aſked, Will it continue at reſt, or will it begin to move? As there is no reaſon which ſhould incline it to move to one ſide rather than to another, it is concluded that it would remain always at reſt. The ſame thing muſt happen, on the ſuppoſition of the exiſtence of other bodies, provided they do not act on the body in queſtion; hence reſults this fundamental law: *When a body is once in a ſtate of reſt, and nothing external acts upon it, it will remain always in that ſtate: and if it begin to move, the cauſe of motion would be out of it, ſo that there is nothing in the body itſelf which is capable of putting it in motion.* When, therefore, we ſee a body which has been at reſt begin to move,

move, we may reſt aſſured that this motion has been occaſioned by an exterior power, as there is nothing in the body itſelf capable of putting it in motion; and if it were alone, and cut off from all communication with other bodies, it would remain always at reſt.

However well founded this law may be, and however entitled to rank with geometrical truths, there are perſons little accuſtomed to profound inveſtigation, who pretend that it is contradicted by experience. They allege the example of a thread, to which a ſtone is appended; the ſtone is at reſt, but falls the moment that the thread is cut. It is certain, ſay they, that the action by which the thread is cut is not capable of making the ſtone move; the ſtone, therefore, muſt fall by a power which is proper to itſelf, and internal.

The fact is certain; but it is evident, at the ſame time, that gravity is the cauſe of the deſcent, and not an internal power in the ſtone.

They ſay farther, that gravity may be an intrinſic power, attached to the nature of the ſtone; on which it muſt be remarked, that gravity is produced either by a ſubtile matter, or by the attraction of the earth. In the firſt caſe it certainly is that ſubtile matter which cauſes the deſcent of the ſtone; in the ſecond, which appears favourable to our opponents, it can with no propriety be affirmed, that the ſtone deſcends by an intrinſic power; it is rather the earth which contains the cauſe of it, and which produces the deſcent of the ſtone, by it's attractive power:

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for if the earth did not exist, or were deprived of it's attractive power, they admit that the stone would not descend.

It is certain, therefore, that the cause of the descent does not reside in the stone itself: the cause, then, is always extrinsic, whether it be in the subtile matter or in the earth, supposing it to be endowed with an attractive power, as the partisans of attraction pretend. This difficulty being removed, the law, which I have laid down, subsists in full force; namely, That a body, once at rest, will always remain so, unless it be put in motion by some foreign cause. This law must take place, provided the body has been at rest but a single instant, though it was in motion immediately before; and, when once reduced to a state of rest, it will always preserve that state, unless some foreign cause intervene to put it again in motion. This principle being the foundation of all mechanics, it was necessary for me to establish it with all possible precision.

28th October, 1760.

LETTER LXXII.

Of uniform, accelerated, and retarded Motion.

I RETURN to the case of a body placed in such a manner as to have no connection with any other. Let us suppose it to have received some motion from whatever cause; it remains that we enquire, What will afterwards happen to it? Will it continue to move? Or will it ſuddenly return to a ſtate of reſt; or after ſome time? You muſt be ſenſible, that this is an enquiry of ſome importance, and that all our reſearches reſpecting the motion of bodies depend upon it. Let us examine if, by means of reaſoning, we are able to reſolve it.

A body is at reſt, as long as it, and all it's parts, remain in the ſame place; and it is in motion when that body, or ſome of it's parts only, paſs from one place to another. Now, there are two things to be conſidered in motion, the direction and the velocity. The direction is the place toward which the body is carried, and the velocity is the ſpace, greater or leſs, through which it moves in a certain time. I am perſuaded you have already juſter ideas of this than I could communicate by the moſt ample explanation. I remark only, that as long as a body preſerves the ſame direction, it moves in a ſtraight line; and reciprocally, as long as a body moves in a ſtraight line, it preſerves the ſame direction; but when it moves in a curve, it is continually changing it's poſition.

If a body, then, (*plate* III. *fig*. 7.) moves in the curve A B C; when it is at A, it's direction is the ſmall line A *a*; when it is at B, it's direction is the ſmall line B *b*; and at C, the ſmall line C *c*. Let theſe ſmall lines be produced; the continuations of which are marked by the ſtraight dotted lines A L, B M, C N; and it will be affirmed, that when the body paſſes through A, it's direction is the ſtraight line A L, becauſe, if the body preſerved the ſame direction which it had at A, it would move in the ſtraight line A L. It is evident, then, that it moves in the curve only in ſo far as it is continually changing it's direction. And when it arrives at B and at C, the direction from which it deviates is expreſſed by the ſtraight lines B M and C N.*

A body preſerves the ſame velocity in it's motion as long at it moves through equal ſpaces in equal times. This motion is called *uniform.* Thus, for example, if a body moves in ſuch a manner as always to proceed ten feet during every ſecond, we call this motion uniform. If another body proceeds twenty feet in a ſecond, it's motion too would be uniform, but it's velocity would be twice as great as that of the preceding.

* The argument, *cauſa ſufficiens*, or *ſufficient reaſon*, is a ſort of jargon introduced by ſome metaphyſicians in the beginning of the preſent century, which has ſtill it's advocates on the continent. To conclude that a thing is ſuch becauſe we ſee no ſufficient reaſon to the contrary, is, indeed, a ſtrange method of reaſoning. What can be more prepoſterous than to employ our ignorance as the inſtrument of diſcovering truth? And yet this is the plain ſtatement of the argument. The inſtance mentioned in the text, is a noted one, though the ingenious Father *Boſcovich* remarks, that any inference whatever may with equal juſtice be drawn from the ſame premiſes. Thus, we may ſay, that no ſufficient reaſon can be given that a moving body A ſhould approach a point B, rather than recede from it; it will, therefore, keep conſtantly at the ſame diſtance, and, conſequently, deſcribe a circle about that point. Hence bodies move not in ſtraight lines, but in circles. In the ſame manner we might ſay that motion is not uniform, and indeed prove any thing we pleaſe. The fact is, that we derive no part of our knowledge from any abſtract reaſoning on the nature of things.

From

From what I have juſt ſaid of the uniformity of motion, it is eaſy to comprehend what is not uniform motion; for when the velocity of a body is not equal, it's motion is not uniform. When the velocity of a body goes on increaſing, it's motion is ſaid to be *accelerated*, and when it is continually diminiſhing, we ſay it is *retarded.* In this laſt caſe, the velocity may come to be retarded to ſuch a degree, that the body ſhall at length come to a ſtate of reſt.

Having made theſe remarks on the velocity and direction of moving bodies, I return to the caſe of a ſolitary body, which I ſuppoſe to be put in motion by any cauſe whatever. As ſoon as it has begun to move, it muſt have acquired a certain direction, and a certain velocity: and the queſtion is, Will it afterwards preſerve the ſame direction and the ſame velocity; or, Will it undergo ſome alteration? We cannot affirm that it will be reduced to a ſtate of reſt in an inſtant, for, in this caſe, it could not have had any motion, all motion ſuppoſing duration, however ſhort. Now, as long as the motion laſts, it is certain that the direction will remain the ſame.

In truth, it is impoſſible to conceive why the body ſhould go out of it's road, to one ſide rather than to another; and, as nothing comes to paſs without reaſon, it follows, that the body in queſtion will always perſevere in the ſame direction, or, that it's motion will proceed in a ſtraight line, which is a great ſtep made toward the deciſion of the queſtion.

It is likewiſe maintained, that the velocity of the body, of which I ſpeak, cannot change: for in that caſe it muſt either increaſe or diminiſh, and no reaſon can be aſſigned capable of producing this change. Hence it is concluded, that this body will always continue to move with the ſame velocity, and in the ſame direction, or that it will proceed continually in the direction of a ſtraight line, without ever deviating from it, and always with equal ſpeed. This motion will be performed, then, always in a ſtraight line, and with an equal velocity, without ever being ſlackened or retarded; the body, therefore, will never be reduced to a ſtate of reſt.

What has been ſaid of a body, which I have ſuppoſed ſolitary, would happen in like manner to our globe, if no other bodies had any influence upon it; for then it would be the ſame thing as if they did not exiſt. The queſtion, then, is reſolved. A body in motion will always preſerve it in the ſame direction, and with the ſame velocity, unleſs ſome external cauſe interpoſe, capable of altering it's motion. So long, therefore, as a body is not ſubject to the action of ſome external cauſe, it will remain at reſt, if it has once been in a ſtate of reſt; or will be moved in the direction of a ſtraight line, and always with the ſame velocity, if it has once been put in motion; and this is the firſt and principal law of nature on which the whole ſcience of motion muſt be founded.

From it we deduce at once this concluſion, that as often as we ſee a body which was at reſt put in motion, or a body moving in a curve line, or whoſe velocity

locity changes, it is certain, that an external cauſe acts upon it. No change can poſſibly take place either as to direction or velocity, but what is the operation of a foreign cauſe.

1ſt November, 1760.

LETTER LXXIII.

Principal Law of Motion and Reſt. Diſputes of Philoſophers on the Subject.

WITH whatever ſolidity this principle is eſtabliſhed, that every body put in motion continues to move in the ſame direction, and with the ſame velocity, unleſs ſome exterior cauſe interpoſe to derange this motion; it has, nevertheleſs, been combated by certain philoſophers, who have never made any great progreſs in the ſcience of motion; while thoſe to whom we are indebted for all the great diſcoveries which have been made in this ſcience, unanimouſly agree, that all their reſearches have proceeded entirely on this principle. It is attacked by two ſects of philoſophers, whoſe objections I proceed to propoſe, and ſhall endeavour to refute.

It is alleged by the one, That all bodies have a propenſity to reſt, which is their natural ſtate, and that motion is to them a ſtate of violence; ſo that when a body is put in motion, it has a tendency, from it's very nature, to return to the ſtate of reſt; and that it makes every effort to deſtroy it's motion, indepen-

independently of every external or foreign cause. They allege, in proof, experience, so convincing, according to them, that we know of no motion in nature that does not very sensibly betray this reluctance. Do we not see, say they, on the billiard table, that with whatever force we strike a ball, it's motion is quickly slackened, and it soon returns to a state of rest. As soon as the motion of a clock ceases to be kept up by the external force which set it a going, it stops. It is remarked of all machines in general, that their motion lasts no longer than the external powers by which they are agitated. Hence they conclude, that a body put in motion is so far from preserving it from any thing in it's own nature, that, on the contrary, an external force must be employed to keep it up.

You must be sensible that, if this conclusion is just, our principle is completely subverted; as, in virtue of this principle, the ball and the machines in question, once put in motion, must always preserve the same, unless external causes have occasioned some change in it. Thus, in the experiments referred to, had there been no external cause which tended to destroy the motion, we should have been under the necessity of abandoning our principle.

But, if we attend to every thing, we shall find so many obstacles opposed to the motion, that we need no longer wonder it should be so speedily extinguished. In fact, it is first the friction on the billiard table which diminishes the motion of the ball, for it cannot advance without rubbing against the cloth.

Again,

Again, the air being a ſubſtance, cauſes likewiſe a reſiſtance capable of diminiſhing the motion of bodies. To be convinced of this, you have only to move your hand rapidly through the air. It is evident, then, that in the caſe of the billiard table, it is the friction and the reſiſtance of the air which counteract the motion of the ball, and ſoon reduce it to a ſtate of reſt.

Now, theſe cauſes are external, and it is eaſily comprehenſible that, but for theſe obſtacles, the motion of the ball muſt have always continued. The ſame reaſoning is applicable to machines of all kinds, in which the friction which acts on the different parts is ſo conſiderable, that it is viſibly a very ſufficient cauſe of ſoon reducing the machine to reſt.

Having, then, diſcovered the real cauſes which produce, in the caſes alleged, the extinction of motion, and that theſe cauſes are external, and not reſident in the moving body, it is evidently falſe, that bodies have in their nature a propenſity to reſt. Our principle, therefore, ſubſiſts in full force, and even acquires additional ſtrength from the preceding objections. Every body, then, always preſerves the motion which it has once received, unleſs foreign cauſes interpoſe to change the direction or the velocity, or both at once. And thus we have got rid of one phalanx of the adverſaries who combat our principle.

The other is more formidable, for they are no leſs than the celebrated Wolſian philoſophers. They do not, indeed, openly declare againſt our principle, nay they

they even expreſs much reſpect for it; but they advance others which directly oppoſe it.

They maintain, That all bodies, in virtue of their nature, are making continual efforts to change their ſtate; that is, when they are at reſt, they make an effort to move; and, if they are in motion, make continual efforts to change their velocity and direction. They allege nothing in proof of this aſſertion, except certain crude reaſonings, drawn from their ſyſtem of metaphyſics, which I ſhall hereafter take occaſion to lay before you. I only remark, at preſent, that this opinion is contradicted by the principle which we have ſo firmly eſtabliſhed; and by experience, which is in perfect conformity with it.

In fact, if it be true that a body at reſt remains, in virtue of it's nature, in that ſtate, it muſt be undoubtedly falſe that it ſhould make, in virtue of it's nature, continual efforts to change it's ſtate. And if it be true that a body in motion preſerves, in virtue of it's nature, this motion, in the ſame direction, and with the ſame velocity, it is impoſſible that the ſame body ſhould, in virtue of it's nature, be making continual efforts to change it's motion.

Theſe philoſophers, in attempting to maintain, at the ſame time, the true principle of motion, and their own abſurd opinion, have fallen into ſelf-contradiction, and thereby ſubverted their own ſyſtem. It is, therefore, placed beyond the reach of diſpute, that our principle is founded in the very nature of body, and that whatever is contrary to it ought to be baniſhed from ſound philoſophy: and this ſame principle

ciple enables us to clear it of certain ſubtilties in which it has been involved.

This principle is commonly expreſſed in the two following propoſitions: Firſt; *A body once at reſt will remain eternally at reſt, unleſs it be put in motion by ſome external or foreign cauſe:* Secondly; *A body once in motion will preſerve it eternally, in the ſame direction, and with the ſame velocity; or will proceed with an uniform motion, in a ſtraight line, unleſs it is diſturbed by ſome external, or foreign cauſe.* In theſe two propoſitions conſiſts the foundation of the whole ſcience of motion, called *mechanics*.

4th November, 1760.

LETTER LXXIV.

Of the Inertia *of Bodies: Of Powers.*

AS we ſay, that a body, ſo long as it is at reſt, remains in the ſame ſtate, ſo we likewiſe ſay of a body in motion, that as long as it moves in the ſame direction, and with the ſame velocity, it remains in the ſame ſtate. To continue in the ſame ſtate, then, ſignifies nothing more than to remain at reſt, or to preſerve the ſame motion.

This manner of ſpeaking has been introduced for the purpoſe of expreſſing more ſuccinctly our grand principle, that every body, in virtue of it's nature, preſerves itſelf in the ſame ſtate, till an extraneous cauſe come to diſturb it, that is, to put the body in motion when at reſt, or to derange it's motion.

It

It muſt not be imagined that a body, in order to preſerve the ſame ſtate, muſt remain in the ſame place; this, indeed, is the caſe when the body is at reſt; but when it moves with the ſame velocity, and in the ſame direction, we ſay, equally, that it continues in the ſame ſtate, though it is every inſtant changing it's place. It was neceſſary to make this remark, to prevent the poſſibility of confounding change of place with that of ſtate. If it be now aſked, Why bodies continue in the ſame ſtate? The anſwer muſt be, that this is in virtue of their peculiar nature.

All bodies, in as far as they are compoſed of matter, have the property of remaining in the ſame ſtate, if they are not drawn out of it by ſome external cauſe. This, then, is a property founded on the nature of bodies, by which they endeavour to preſerve themſelves in *the ſame ſtate*, whether of reſt or motion. This quality with which all bodies are endowed, and which is eſſential to them, is called *inertia*,* and it enters as neceſſarily into their conſtitution as extenſion and impenetrability; to ſuch a de-

* We have already in common uſe, in our own language, the adjective *inert*, and the adverb *inertly*, and their meaning is generally underſtood. But hitherto no author of name, except in works philoſophy, has ventured to introduce the correſpondent ſub- ive noun into general compoſition, much leſs to clothe it with nglish form. The Latin term *inertia* is, therefore, retained in ranſlation. The linguiſt and the philoſopher need no inter- ion. The unlearned reader is referred to what Mr. Euler n the context, or to the explanation of foreign and ſcientific s affixed to this work.—*E. E.*

gree,

gree, that it would be impoſſible for a body to exiſt, diveſted of this *inertia*.

This term was firſt introduced into philoſophy by thoſe who maintained that all bodies have a propenſity to reſt. They conſidered bodies as ſomewhat reſembling indolent perſons, who prefer reſt to exertion, and aſcribed to bodies an averſion to motion, ſimilar to that which ſluggards have for labour; the term *inertia* ſignifying nearly the ſame thing as ſluggiſhneſs. But though the falſeneſs of this opinion has been ſince detected, and though it is certain that bodies remain equally in their ſtate of motion, as in that of reſt, yet the term *inertia* has been ſtill retained to denote in general the property of all bodies to continue in the ſame ſtate, whether of reſt or of motion.*

The exact idea of *inertia*, therefore, is a repugnance to every thing that has a tendency to change the ſtate of bodies; for as a body, in virtue of it's nature, preſerves the ſame ſtate of motion, or of reſt, and cannot be drawn out of it but by external cauſes, it follows that, in order to a body's changing it's

* The diſtinguiſhing property of inanimate matter is it's abſolute paſſiveneſs or want of diſpoſition to change it's ſtate, whether that of reſt, or of motion. The term *inertia* is improper, ſince it conveys an idea of ſluggiſhneſs, or a reluctance to be put in motion; whereas bodies are obedient to the ſmalleſt impulſe, and the action generated is ever proportioned to the force. The expreſſion *vis inertiæ*, commonly uſed, is really a contradiction of terms. Indeed, it would be no diſſervice to natural philoſophy, if the law that "action and re-action are equal and oppoſite," were entirely omitted.—*E. E.*

ſtate,

ſtate, it muſt be forced out of it by ſome external cauſe: without which it would always continue in the ſame ſtate. Hence it is, that we give to this external cauſe the name of *power* or *force*. It is a term in common uſe, though many by whom it is employed have but a very imperfect idea of it.

From what I have juſt ſaid you will ſee that the word *force* ſignifies every thing that is capable of changing the ſtate of bodies. Thus, when a body which has been at reſt is put in motion, it is a force which produces this effect; and when a body in motion changes it's direction, or velocity, it is likewiſe a force which produces this change. Every change of direction, or of velocity, in the motion of a body, requires either an increaſe or a diminution of force. Such force, therefore, is always out of the body whoſe ſtate is changed; for we have ſeen that a body left to itſelf, preſerves always the ſame ſtate, unleſs a force from without acts upon it.

Now, the *inertia* by which a body tends to preſerve itſelf in the ſame ſtate, exiſts in the body itſelf, and is an eſſential property of it: when, therefore, an external force changes the ſtate of any body, the *inertia* which would maintain it in the ſame ſtate, oppoſes itſelf to the action of that force; and hence we comprehend, that the *inertia* is a quality ſuſceptible of meaſurement, or that the *inertia* of one body may be greater or leſs than that of another body.

But bodies are endowed with this *inertia* in as far as they contain matter. It is even by the *inertia*, or the reſiſtance which they oppoſe to every change of ſtate,

ſtate, that we judge of the quantity of a body; the *inertia* of a body, accordingly, is greater in proportion to the quantity of matter which it contains. Hence we conclude, that it requires a greater force to change the ſtate of a great body, than that of a ſmall one; and we go on to conclude, that the great body contains more matter than the ſmall one. It may even be affirmed that this ſingle circumſtance, the *inertia*, renders matter ſenſible to us.

It is evident, then, that the *inertia* is ſuſceptible of meaſurement, and that it is the ſame with the quantity of matter which a body contains: as we denominate, likewiſe, the quantity of matter in a body, it's maſs, the meaſure of the *inertia* is the ſame as that of the maſs.

To this, then, is reduced our knowledge of bodies in general. Firſt, we know, that all bodies have an extenſion of three dimenſions; ſecondly, that they are impenetrable; and hence reſults their general property, known by the name of *inertia*, by which they preſerve themſelves in their ſtate; that is, when a body is at reſt, by it's *inertia* it remains ſo; and when it is in motion, it is likewiſe by it's *inertia* that it continues to move with the ſame velocity, and in the ſame direction; and this preſervation of the ſame ſtate laſts till ſome external cauſe interpoſe to produce a change in it. As often as the ſtate of a body changes, we muſt never look for the cauſe of ſuch change in the body itſelf; it exiſts always out of the body, and this is the juſt idea which we muſt form of a power or force.

8th November, 1760.

LETTER LXXV.

Changes which may take place in the State of Bodies.

THE fundamental principle of mechanics, with the idea of *inertia*, which I have endeavoured to explain, enables us to reafon on folid ground refpecting various phenomena prefented to us in nature. On feeing a body in motion, which fhould proceed uniformly in a ftraight line, that is, which fhould preferve the fame direction, and the fame velocity, we would fay, that the caufe of this continuation of motion is not to be found out of the body, but that it is founded in it's very nature, and that, in virtue of it's *inertia*, it remains always in the fame ftate; as we would fay, were the body at reft, that this took place in virtue of it's *inertia*.

We would likewife be right in faying that this body undergoes no action from any external caufe; or, if any fuch exifted, that thefe powers reciprocally deftroyed each other in fuch a manner that the body is in the ftate in which it would be if no force acted upon it.

If it is afked, then, Why the body continues to move in this manner? The anfwer is obvious. But if it is afked, Why this body has begun thus to move? The queftion is totally different. It muft be faid, that this motion has been impreffed upon it by fome external force, if it was before at reft; but it would be impoffible to affirm any thing with certainty

tainty respecting the quantity of that force, because, perhaps, no traces of it remain. It is, therefore, abundantly ridiculous to ask, Who impressed motion on every body at the beginning of the world? Or, Who was the prime mover? Those who put the question admit, then, a beginning, and, consequently, a creation; but they imagine that God created all bodies at rest. Now, it may be answered, That he who could create bodies could impress motion upon them. I ask them, in my turn, If they believe it to be more easy to create a body at rest than in motion? They both equally require the omnipotence of God, and this question belongs not to the province of philosophy.

But when a body has once received motion, it preserves that motion by it's own nature, or by it's *inertia*, in the same state in which it must constantly remain, until a force, or some foreign cause, oppose an obstacle to it. As often, then, as we observe that a body does not remain in the same state, that a body at rest begins to move, or that a body in motion changes it's direction, or velocity, we must admit that this change has it's cause out of the body, and that it is occasioned by a foreign force. Thus, as a stone, left to itself, descends, the cause of that descent is foreign to the body, and it is not from it's own nature that the body descends, but from the effect of a foreign cause, to which we give the name of *gravity*.

Gravity, then, is not an intrinsic property of body;

 it

it is rather the effect of a foreign force, the source of which must be sought for out of the body. This is geometrically true, though we know not the foreign forces which occasion gravity. It is the same when we throw a stone. We see clearly, that it does not follow, in it's motion, the direction of a straight line, and that it's velocity does not always continue the same. It is gravity, likewise, which changes the direction or the velocity of the body; but for it, the stone would describe a straight line in the air, and proceed forward with the same velocity; and were gravity to be suddenly annihilated, during the motion of the stone, it would continue to move in a straight line, and would preserve the same direction, and the same velocity, which it had at the instant when gravity ceased to act upon it.

But as gravity acts continually, and upon all bodies, we need not be surprized, that we meet with no motion in which the direction and the velocity continue the same. The case of rest may very well take place; it is when something invincibly opposes the fall of a body; thus the floor of my apartment prevents my falling into that below it. But the bodies which appear to us at rest, are carried along by the motion of the earth, which is neither rectilinear nor uniform: it cannot be affirmed, therefore, that these bodies remain in the same state. Neither is there one of the heavenly bodies which moves in a straight line, and always with the same velocity: they are continually changing their state; and even the forces which produce

duce this continual change are not unknown to us; they are the attractive powers which the heavenly bodies exercife over one another.

I have already remarked, that thefe forces may, very probably, be caufed by the fubtile matter which furrounds all the heavenly bodies, and fills the whole fpace of the heavens; but, according to the opinion of thofe who confider attraction as a power inherent in matter, this force is always foreign to the body on which it acts. Thus, when we fay the earth is attracted toward the fun, it is acknowledged, that the force which acts upon the earth is not refident in the earth itfelf, but in the fun; as in fact, if the fun did not exift, there would be no fuch force.

This opinion, however, that attraction is effential to all matter, is fubject to fo many other inconveniences, that it is hardly poffible to allow it a place in a rational philofophy. It is certainly much fafer to proceed on the idea, that what is called attraction, is a power contained in the fubtile matter which fills the whole fpace of the heavens; though we cannot tell how. We muft accuftom ourfelves to acknowledge our ignorance on a variety of other important fubjects.

11th November, 1760.

LETTER LXXVI.

System of the Monads of Wolff.

BEFORE I attempt to make you ſenſible of the truth of the principle, that all bodies, of themſelves, always preſerve the ſame ſtate of reſt, or motion, I muſt remark, that if we conſult experience only on the ſubject, without thoroughly inveſtigating it by the powers of reaſoning, we would be diſpoſed to draw the directly oppoſite concluſion, and to maintain, That bodies always have a propenſity to be continually changing their ſtate; as we ſee nothing in the whole univerſe, but a perpetual change in the ſtate of bodies. But we have juſt ſhewn what are the cauſes which produce theſe changes, and we are aſſured, that they are not to be found in the bodies whoſe ſtate is changed, but out of them.

The principle, then, which we have eſtabliſhed, is ſo far from being contradicted by experience, that it is, on the contrary, confirmed by it. You will eaſily judge from this, how ſeveral great philoſophers, miſled by an experience not accurately underſtood, have fallen into the error of maintaining, That all bodies are endowed with powers, diſpoſing them continually to change their ſtate.

It is thus that *Wolff* has reaſoned. He ſays: 1. Experience ſhews us all bodies perpetually changing their ſtate; 2. Whatever is capable of changing the ſtate of bodies, is called force; 3. All bodies, therefore,

fore, are endowed with a force capable of changing their ſtate; 4. Every body, therefore, is making a continual effort to change; 5. Now, this force belongs to body, only ſo far as it contains matter; 6. It is, therefore, a property of matter to be continually changing it's own ſtate; 7. Matter is a compound of a multitude of parts, denominated the elements of matter; therefore, 8. As the compound can have nothing but what is founded in the nature of it's elements, every elementary part muſt be endowed with the power of changing it's own ſtate.

Theſe elements are ſimple beings; for if they were compoſed of parts, they would be no longer elements, but their parts would be ſo. Now, a ſimple being is likewiſe denominated *monad*; every monad, therefore, has the power of continually changing it's ſtate. Such is the foundation of the ſyſtem of monads, which you may have heard mentioned, though it does not now make ſuch a noiſe as it formerly did. I have marked by figures the ſeveral propoſitions on which it is eſtabliſhed, for the purpoſe of making a more diſtinct reference, in the reflections I mean to make upon them.

I have nothing to ſay reſpecting the firſt and ſecond; but the third is very equivocal, and altogether falſe, in the ſenſe in which it is taken. Without meaning to ſay, that the forces which change the ſtate of bodies, proceed from ſome ſpirit, I readily agree, that the force, by which the ſtate of every body is changed, ſubſiſts in body, but, it being always underſtood, that it ſubſiſts in another body, and never in that which undergoes the change of ſtate; which has rather the contrary quality, that of perſevering in the ſame ſtate. In ſo far, then, as theſe forces ſubſiſt in bodies, it ought to be ſaid, that theſe bodies, as long as they have certain connections with each other, may be capable of ſupplying forces by which the ſtate of another body is changed. It follows, that the fourth propoſition muſt be abſolutely falſe; and the reſult, from all that went before, rather is, that every body is endowed with the power of remaining in the ſame ſtate, which is directly the oppoſite of the concluſion which theſe philoſophers have drawn.

And I muſt here remark, that it is rather abſurd to give the name of *force* to that quality of bodies by which they remain in their ſtate; for if we are to underſtand by the term *force* every thing that is capable of changing the ſtate of bodies, the quality by which they perſevere in their ſtate, is rather the oppoſite of a force. It is, therefore, by an abuſe of language, that certain authors give the name of force to the *inertia*, which is that quality, and which they denominate the *inert force*.

But, not to wrangle about terms, though this abuſe may lead to very groſs errors, I return to the ſyſtem of monads: and as propoſition 4, is falſe, thoſe that follow, which are ſucceſſively founded upon it, muſt, of neceſſity, be ſo too. It is falſe, then, likewiſe, that the elements of matter, or monads, if ſuch there be, are poſſeſſed of the power of changing their ſtate. The truth is rather to be founded in the oppoſite quality,

quality, that of perfevering in the fame ftate; and thereby the whole fyftem of monads is completely fubverted.

Thefe philofophers attempted to reduce the elements of matter to the clafs of *beings*, which comprehends fpirits and fouls, endowed, beyond the power of contradiction, with the faculty of changing their ftate; for, while I am writing, my foul continually reprefents other objects to itfelf, and thefe changes depend entirely on my will: I am thoroughly convinced of it, and not the lefs fo, that I am mafter of my own thoughts; whereas the changes which take place in bodies, are the effect of an extraneous force.

Add to this, the infinite difference between the ftate of body, capable only of one velocity and of one direction, and the thoughts of fpirit, and you will be entirely convinced of the falfehood of the fentiments of the materialifts, who pretend that fpirit is only a modification of matter. Thefe gentlemen have no knowledge of the real nature of bodies.

15th November, 1760.

LETTER LXXVII.

Origin and Nature of Powers.

IT is, undoubtedly, very furprizing, that, if every body has a natural difpofition to preferve itfelf in the fame ftate, and even to oppofe all change, all the bodies in the univerfe fhould, neverthelefs, be continually changing their ſtate. We are well aſſured, that this change can be produced only by a force not reſident in the body whoſe ſtate is changed. Where, then, muſt we look for thoſe powers, which produce the inceſſant changes that take place in all the bodies of the univerſe; and which are, nevertheleſs, foreign to body?

Muſt we then ſuppoſe, beſides theſe exiſting bodies, particular beings which contain thoſe powers? Or, are the powers themſelves particular ſubſtances exiſting in the world? We know but of two kinds of beings in it, the one which comprehends all bodies, and the other all intellectual beings, namely, the ſpirits and ſouls of men, and thoſe of animals. Muſt we eſtabliſh, then, in the world, beſides body and ſpirits, a third ſpecies of beings, under the name of power, or force? Or, are they ſpirits which inceſſantly change the ſtate of bodies?

Both of theſe labour under too many difficulties to be haſtily adopted. Though it cannot be denied, that the ſouls of men, and of beaſts, have the power of producing changes in their bodies, it were, however, abſurd to maintain, that the motion of a ball, illiard table, was retarded and deſtroyed by ; or that gravity was produced by a ſpirit ng bodies downward; and that the hich, in their motion, change both ity, were ſubjected to the action g to the ſyſtem of certain ancient aſſigned to each of the heavenly angel, who directed it's courſe.

Now,

Now, on reaſoning with ſolidity, reſpecting the phenomena of the univerſe, it muſt be admitted, that, if we except animated bodies, that is, thoſe of men and beaſts, every change of ſtate which befalls other bodies, is produced by merely corporeal cauſes, in which ſpirits have no ſhare. The whole queſtion, then, is reduced to this, Whether the forces which change the ſtate of bodies, exiſt ſeparately, and conſtitute a particular ſpecies of beings, or whether they exiſt in the bodies?

This laſt opinion appears, at firſt ſight, very unaccountable; for if all bodies have the power of preſerving themſelves in the ſame ſtate, how can it be poſſible they ſhould contain powers that have a tendency to change it? You will not be ſurprized to hear, that the origin of force has, in all ages, been a ſtumbling-block to philoſophers. They have all conſidered it as the greateſt myſtery in nature, and as likely to remain for ever impenetrable. I hope, however, I ſhall be able to preſent you with a ſolution, ſo clear of this pretended myſtery, that all the difficulties which have hitherto appeared inſurmountable, ſhall wholly vaniſh.

I ſay, then, that however ſtrange it may appear, this faculty of bodies, by which they are diſpoſed to preſerve themſelves in the ſame ſtate, is capable of ſupplying powers which may change that of others. I do not ſay, that a body ever changes it's own ſtate, but that it may become capable of changing that of another. In order to enable you to get to the bottom of this myſtery, reſpecting the origin of force, it it will be ſufficient to conſider two bodies, as if no others exiſted.

Let the body A (*plate* III. *fig.* 4.) be at reſt, and let the body B have received a motion in the direction B A, with a certain velocity. This being laid down, the body A is diſpoſed to continue always at reſt; and the body B to continue it's motion along the ſtraight line B A, always with the ſame velocity, and both the one and the other in virtue of it's *inertia.* The body B will, at length, then come to touch the body A. What will be the conſequence? As long as the body A remains at reſt, the body B could not continue it's motion, without paſſing through the body A, that is, without penetrating it; it is impoſſible, then, that each body ſhould preſerve itſelf in it's ſtate, without the one's penetrating the other. But this penetration is impoſſible; impenetrability being a property common to all bodies.

It being impoſſible, then, that both the one and the other ſhould preſerve it's ſtate, the body A muſt abſolutely begin to move, to make way for the body B, that it may continue it's motion; or, that the body B, having come cloſe to the body A, muſt have it's motion deſtroyed; or, the ſtate of both muſt be changed, as much as is neceſſary, to put them in a dition to continue, afterward, each in his proper without mutual penetration.

her the one body, therefore, or the other, or , muſt abſolutely undergo a change of their ; and the cauſe of this change, infallibly exiſts in impenetrab ility of the bodies themſelves; ſince every

every cauſe, capable of changing the ſtate of bodies, is demonſtrated *force*, it is then, of neceſſity, the impenetrability of the bodies themſelves, which produces the force, by which this change is effected.

In fact, as impenetrability implies the impoſſibility, that bodies ſhould mutually penetrate, each of them oppoſes itſelf to all penetration, even in the minuteſt parts; and to oppoſe itſelf to penetration, is nothing elſe, but to exert the force neceſſary to prevent it. As often, then, as two or more bodies cannot preſerve themſelves in their ſtate, without mutual penetration, their impenetrability always exerts the force neceſſary to change it, as far as is requiſite, to prevent the ſlighteſt degree of penetration.

The impenetrability of bodies, therefore, contains the real origin of the forces, which are continually changing their ſtate in this world: and this is the true ſolution of the great myſtery, which has perplexed philoſophers ſo grievouſly.

18th November, 1760.

LETTER LXXVIII.

The ſame Subject. Principle of the leaſt poſſible Action.

YOU have now made very conſiderable progreſs in the knowledge of nature, from the explanation of the real origin of the powers capable of changing the ſtate of bodies; and you are, at preſent, in a condition eaſily to comprehend, why all thoſe

When, therefore, a ſmall force ſuffices to prevent penetration, impenetrability exerts that, and no more; but when a great force is neceſſary for this purpoſe, impenetrability is ever in a condition to ſupply it.

Thus, though impenetrability ſupplies theſe powers, it is impoſſible to ſay, that it is endowed with a determinate force; it is rather in a condition to ſupply all kinds of force, great or ſmall, according to circumſtances; it is even an inexhauſtible ſource of them. As long as bodies are endowed with impenetrability, this is a ſource which cannot be dried up; this force abſolutely muſt be exerted, or bodies muſt mutually penetrate, which is contrary to nature.

It ought, likewiſe, to be remarked, that this force is never the effect of the impenetrability of a ſingle body; it reſults always from that of all bodies at once, for if one of the bodies was penetrable, the penetration would take place, without any need of a power to effect a change in their ſtate. When, therefore, two bodies come into contact, and when they cannot continue in their ſtate without penetrating each other, the impenetrability of both acts equally; and it is by their joint operation, that the force neceſſary to prevent the penetration is ſupplied: we then ſay, that they act upon each other, and that the force, reſulting from their impenetrability, produces this effect. This force acts upon both of them; for as they have a tendency toward mutual penetration, it repels both the one and the other, and thus prevents their penetration.

It is certain, then, that bodies may act upon each other; and we speak so frequently of this action, as when two billiard balls clash, it is said, the one acts upon the other, that you must be well acquainted with this mode of expression. But it must be carefully remarked, that, in general, bodies do not act upon each other, but in so far as their state becomes contrary to impenetrability; from whence results a force capable of changing it, precisely so much as is necessary to prevent any penetration; so that a small force would not have been sufficient to produce this effect.

It is very true, that a greater force would, likewise, prevent the penetration; but when the change produced in the state of bodies is sufficient to prevent mutual penetration, the impenetrability acts no farther, and there results from it the least force that is capable of preventing the penetration. Since, then, the force is the smallest, the effect which it produces, that is, the change of state which it operates, in order to prevent penetration, will be proportional; and, consequently, when two or more bodies come into contact, so that no one could continue in it's state without penetrating the others, a mutual action [illegible] take place, which is always the smallest that [illegible] of preventing penetration.

[illegible] find here, therefore, beyond all expecta[illegible] [illegible]ndation of the system of the late Mr. [illegible], so much cried up by some, and so vio[illegible] [illegible]d by others. His principle is, that of the

the leaſt poſſible action; by which he means, that, in all the changes which happen in nature, the cauſe which produces them, is the leaſt that can be.

From the manner in which I have endeavoured to unfold this principle to you, it is evident, that it is perfectly founded in the very nature of body, and that thoſe who deny it, are much in the wrong, though ſtill leſs than thoſe who would turn it into ridicule. You will already, perhaps, have remarked, that certain perſons, no great friends to Mr. *de Maupertuis*, take every opportunity of laughing at the principle of *the leaſt poſſible action*, as well as at the hole continued down to the centre of the earth; but, fortunately, truth ſuffers nothing by their pleaſantry.

22d Nov. 1760.

LETTER LXXIX.

On the Queſtion, Are there any other Species of Powers?

THE origin of powers, founded on the impenetrability of bodies, which I have been endeavouring to explain, is by no means inconſiſtent with the opinion of thoſe who maintain, that the ſouls of men, and thoſe of beaſts, have the power of acting on their bodies. There is nothing to hinder the exiſtence of two kinds of power, which produce all the changes that take place in the world; the one corporeal, which derives it's origin from the impenetrability

netrability of bodies: and the other ſpiritual, which the ſouls of animals exerciſe over their bodies: but this laſt power operates only upon animated bodies; and the Creator has ſo clearly diſtinguiſhed it from the other, that it is not permitted, in philoſophy, to confound them.

But this diſtinction greatly embarraſſes thoſe, who conſider attraction as an inherent quality of bodies; for, if they act upon each other, only to maintain their impenetrability, attraction cannot be referred to this caſe. Two diſtant bodies may preſerve each it's ſtate, without at all intereſting their impenetrability, and without there being any reaſon, of conſequence, why the one ſhould act upon the other, even by attracting it.

Attraction, therefore, ought to be referred to a third ſpecies of power, which ſhould be neither corporeal nor ſpiritual. But it is always contrary to the rules of a rational philoſophy to introduce a new ſpecies of powers, before their exiſtence is inconteſtably demonſtrated. It would have been neceſſary, therefore, for this effect, to have proved, beyond contradiction, that the powers by which bodies mutually attract, could not derive their origin from the btile matter which ſurrounds them; but this imſſibility is not yet demonſtrated. It would appear, the contrary, that the Creator has expreſsly filled whole ſpace of the heavens with a ſubtile matter, give birth to theſe powers, which impel bodies tord each other, conformably to the law, before iſhed, reſpecting their impenetrability.

In

In fact, the subtile matter might very well have a motion such as that a body in it should not be able to preserve it's state, without being penetrated by it; and then this force must be derived, as well from the impenetrability of the subtile matter, as from that of the body itself.

Were there a single case in the world, in which two bodies attracted each other, while the intermediate space was not filled with a subtile matter, the reality of attraction might very well be admitted; but as no such case exists, we have, consequently, reason to doubt, nay, even to reject it. We know, then, but two sources of all the powers which produce these changes, the impenetrability of body, and the action of spirit.

The disciples of *Wolff* reject, likewise, this law, and maintain, That no spirit, or immaterial substance, can act upon a body; and they are very much embarrassed, when it is alleged, that, according to them, God himself, who is a spirit, could not have the power of acting upon bodies, which savours strongly of atheism. They are, accordingly, reduced to this feeble reply, that it is by *infinity* God is able to act upon body; but if it be impossible for a spirit, as a spirit, to act upon a body, this impotence necessarily recoils on God himself. And who can deny, that our soul acts upon our body? I am to such a degree master of my members, that I can put them in action as I please. The same thing may be affirmed, likewise, of the brute creation; and as, according to the system of *Descartes*, at which we have good reafon to fmile, beafts are mere machines, without any feeling, like a watch, as the Wolfians would have it, men too are merely machines.

Thefe fame philofophers, in their fpeculations, go, likewife, fo far as to deny the firft fpecies of powers, of which they know nothing. For, not being able to comprehend how one body acts upon another, they boldly deny it's action, and maintain, that all the changes which befall a body, are produced by it's own powers.

They are the philofophers whom I formerly mentioned, as denying the firft principle of mechanics, refpecting the prefervation of the fame ftate, which is fufficient to fubvert their whole fyftem. The error into which they have fallen, as I have already remarked, arifes from their reafoning inconclufively refpecting the phenomena which bodies prefent to us. They concluded precipitately, from obferving almoft all bodies continually changing their ftate, that they contained in themfelves the powers, by which they inceffantly exert themfelves to change it, whereas they ought to have drawn the directly oppofite conclufion.

It is thus, that, by confidering objects in a fuperficial manner, we hurry into the groffeft errors. I have already pointed out the defects of this reafoning; but, once fallen into error, they have abandoned themfelves to the moft abfurd ideas. They, firft, afcribed thefe internal powers to the primary elements of matter, which, according to them, are continual efforts to change their ftate, and concluded from

from it, that all the changes to which every element is ſubjected, are produced by it's own power, and that two elements, or ſimple beings, cannot act upon each other. This being laid down, it was neceſſary to diveſt ſpirits, as ſimple beings, of all power of acting upon body, excepting, however, the Supreme Being; and then, as bodies are compoſed of ſimple beings, they were under the neceſſity of denying, alſo, that bodies could act upon each other.

It was in vain to object to them, the caſe of bodies which claſh, and the change of their ſtate, which reſults from it. Obſtinately prepoſſeſſed in favour of the ſolidity of their reaſoning, they ſcorned to abandon it: they choſe rather to affirm, that every body, from it's own nature, produces the change which befalls it, and that the colliſon has nothing to do with it; that it is a mere illuſion which makes us believe the colliſon to be the cauſe of it; and they go off in triumph at the ſublimity of a philoſophy, ſo far beyond the comprehenſion of the vulgar. You are now in a condition to eſtimate it, according to it's real importance.

25th November, 1760.

LETTER LXXX.

Of the Nature of Spirits.

I FLATTER myſelf, that you are now convinced of the ſolidity of the reaſonings, on which I have eſtabliſhed the knowledge of bodies, and that of the powers which change the ſtate of them. The whole is founded on experiments the moſt deciſive, and on principles dictated by reaſon. They involve no abſurdity, nor are they contradicted by other principles, equally certain. It is not long ſince any ſucceſsful progreſs was made in reſearches of this kind. Such ſtrange ideas were, formerly, entertained reſpecting the nature of bodies, that all kinds of powers were aſcribed to them, of which ſome muſt neceſſarily deſtroy the others.

Certain philoſophers have even gone ſo far, as to imagine, that matter itſelf might be endowed with the faculty of thought. Theſe gentlemen, known by the name of *materialiſts*, maintain, that our ſouls, and all ſpirits, in general, are material; or rather, they deny the exiſtence of ſouls and ſpirits. But when once we have got into the right road to the knowledge of bodies; the *inertia*, by virtue of which they continue in their ſtate; and *impenetrability*, that quality by which they are ſubjected to powers capable of changing it; all thoſe phantoms of powers, to which I alluded, vaniſh away, and nothing appears a more glaring abſurdity than to affirm, that matter is capable of thought. To think, to judge, to reaſon, to poſſeſs mental feeling, to reflect and will, are qualities incompatible with the nature of bodies; and beings inveſted with them, muſt be of a different nature. Such are ſouls and ſpirits; and He who poſſeſſes thoſe qualities in the higheſt degree, is GOD.

There is, then, an infinite difference between body and ſpirit. Extenſion, *inertia*, and impenetrability, qualities

qualities which exclude all thought, are the properties of body: but ſpirit is endowed with the faculty of thinking, of judging, of reaſoning, of feeling, of reflecting, of willing, or of determining, in favour of one object preferably to another. There is here neither extenſion, nor *inertia*, nor impenetrability; theſe material qualities are infinitely remote from ſpirit.

It is aſked, What is a ſpirit? I acknowledge my ignorance in reſpect of this, and I reply, That we cannot tell what it is, as we know nothing of the nature of ſpirit.

But it is not the leſs certain, that this world contains two kinds of beings; beings *corporeal* or *material*, and beings *immaterial* or *ſpiritual*, which are of a nature entirely different, as they manifeſt themſelves to us by properties which have no relation to each other. Theſe two ſpecies of beings are, nevertheleſs, moſt intimately united, and upon their union, principally, depend all the wonders of the world, which are the delight of intelligent beings, and lead them to glorify their CREATOR.

It is certain, that ſpirits conſtitute the principal part of the world, and that bodies are introduced into it merely to ſerve them. For this reaſon it is, that the ſouls of animals are in an union ſo intimate with their bodies. Not only do the ſouls perceive all the impreſſions made upon their bodies; but they have the power of acting upon theſe bodies, and of producing in them correſponding changes: and thus

LETTER LXXXII.

Different Syſtems, relative to this Subject.

IN order to elucidate the twofold union of ſoul and body, we may compare the ſoul to a man, who contemplates, in a dark room, the external objects, and from their images derives the knowledge of what is paſſing out of the room. The ſoul viewing, in like manner, if I may ſo expreſs myſelf, the extremities of the nerves, which unite in a certain part of the brain, perceives all the impreſſions made upon the nerves, and arrives at the knowledge of the external objects, which have made theſe impreſſions on the organs of ſenſe. Though we do not know wherein conſiſts the reſemblance of the impreſſions made on the extremities of the nerves, with the objects themſelves which occaſioned them, they are, however, very proper to ſupply the ſoul with a very juſt idea of them.

The action by which the ſoul, operating on the extremities of the nerves, can put in motion, at pleaſure, the members of the body, may be compared to that of a player on puppets, who, by pulling a ſtring, makes them ſtrut about, and move their limbs as he pleaſes. This compariſon is, however, very imperfect, for the union of the ſoul and body is infinitely more intimate.

The ſoul is not ſo indifferent, in reſpect of feeling, the man placed in the dark room; it is much more deeply

deeply interefted in what is going on. There are fenfations highly agreeable to it, and others very difagreeable, and even painful. What more difagreeable than acute pain, though it proceed but from a bad tooth? This, however, is no more than a nerve irritated in a certain manner, and yet it excites, in the foul, pain intolerable.

In whatever light we confider the ftrict union of foul and body, which conftitutes the effence of a living man, it muft ever remain an inexplicable myftery; and, in all ages, philofophers have taken fruitlefs pains, in the hope of arriving at a fatisfactory folution. Various fyftems have been devifed in this view.

The firft is, that by which a real influence is eftablifhed of body on foul, and of foul on body; fo that the body, by means of the fenfes, fupplies the foul with it's firft perceptions of external things; and that the foul, by acting immediately on the nerves, in their origin, excites in the body the motion of it's members; though it is, at the fame time, acknowledged, that the manner of this mutual influence is abfolutely unknown to us. We muft, undoubtedly, have recourfe to the omnipotence of God, who has given to every foul, a power over the portion of matter containing the extremities of the nerves of the body, fo that the power of every foul is reftricted to a fmall part of the body, whereas the power of God extends to all the bodies of the univerfe. This fyftem feems the moft conformable to truth, though we are very far from pretending to have a particular knowledge of it.

The

The other two fyftems are the invention of philofophers, who boldly deny the poffibility of a real influence of fpirit upon bodies; though they are under the neceffity of allowing it to the Supreme Being. According to them, the body cannot fupply the foul with the firft ideas of external things, nor the foul produce any motion in the body.

One of thefe two fyftems was the invention of *Defcartes*; it goes by the name of *the fyftem of occafional caufes*. According to this philofopher, when the organs of fenfe are excited by exterior bodies, God immediately impreffes on the foul, at the fame inftant, the ideas of thefe bodies; and when the foul wills, that any member of this body fhould move, ftill it is God, who immediately impreffes, on that member, the motion defired, but all the while, the foul is in no manner of connection with it's body. It was, therefore, altogether unneceffary, that the body fhould be a machine of fuch admirable conftruction, as the dulleft mafs would have anfwered the purpofe equally well.

This fyftem, accordingly, foon loft much of it's credit, when the celebrated *Leibnitz* fubftituted, in it's place, that of the pre-eftablifhed harmony, which you have, no doubt, frequently heard mentioned in converfation.

According to this fyftem of *pre-eftablifhed harmony*, the foul and the body are two fubftances out of all connection, and exercifing no manner of influence on each other. The foul is a fpiritual fubftance, which, from it's own nature, receives, or affumes, all it's ideas,

ideas, it's thoughts, it's perceptions, without the body's having the leaſt ſhare in the matter; and the body is a machine moſt ingeniouſly conſtructed, like a clock, which produces all it's motions, in ſucceſſion, without any manner of influence on the part of the ſoul. But God, having foreſeen, from the beginning, all the reſolutions, which every ſoul would at every inſtant form, arranged the machine of the body, ſo as that it's motions ſhould, at every inſtant, harmonize with the reſolutions of the ſoul. Thus, when I at this moment raiſe my hand, *Leibnitz* ſays, that God having foreſeen my ſoul would will, at this moment, my hand to be raiſed, diſpoſed the machine of my body in ſuch a manner, that, in virtue of it's proper organization, my hand ſhould neceſſarily riſe at the ſame inſtant; and, in like manner, that all the motions of the members of the body are performed in virtue of their proper organization, which has been, from the beginning, ſo diſpoſed, as to be at all times in harmony with the determinations of the ſoul.

6th December, 1760.

LETTER LXXXIII.

Examination of the Syſtem of pre-eſtabliſhed Harmony. An Objection to it.

THERE was a time, when the ſyſtem of pre-eſtabliſhed harmony had acquired ſuch a high reputation over all Germany, that to dare to call it in in queſtion was to incur the imputation of ignorance, or bigotry. The ſupporters of this ſyſtem boaſted, that, by means of it, the omnipotence and omniſcience of the Supreme Being were ſet in their cleareſt light, and that it was impoſſible for any one, who believed in theſe exalted perfections of God, to entertain a doubt of the truth of this ſublime ſyſtem.

In fact, ſay they, we ſee, that poor, pitiful mortals, are capable of conſtructing machines ſo ingeniouſly, as to fill the vulgar ſpectator with aſtoniſhment: how much ſtronger reaſon, then, have we to admit, that God having known, from all eternity, all that my ſoul would wiſh and deſire, at every inſtant, ſhould have been able to conſtruct ſuch a machine, which, at every inſtant, ſhould produce motions conformable to the determinations of my ſoul? Now, this machine is preciſely my body, which is united to my ſoul, only by this harmony; ſo that if the organization of my body were deranged to ſuch a degree, as to be no longer in harmony with my ſoul, this body would no more belong to me, than the body of a rhinoceros in the heart of Africa: and if, in the caſe of a derangement of my body, God ſhould adjuſt that of a rhinoceros, ſo that it's motions were in ſuch harmony with the determinations of my ſoul, as to raiſe it's paw at the moment I willed it; this body would then be mine, and would belong to my ſoul, as my preſent body now belongs to it, without having undergone itſelf, on that account, any change whatever.

Mr. *Leibnitz* himſelf has compared the ſoul and the

body,

body to two clocks, which continually indicate the ſame hour. A clown who ſhould ſee this beautiful harmony of theſe two clocks, would undoubtedly conclude, that they acted upon each other, but he would be under a miſtake, for the one performs it's motions independently of the other. The ſoul and the body are likewiſe two machines totally independent, the one being ſpiritual, the other material; but their operations are always in a harmony ſo complete, that we are induced to believe them to belong to each other, and that the one has a real influence upon the other, which is, however, a mere illuſion.

In order to form a judgment of this ſyſtem, I remark, firſt, That it cannot be denied to be poſſible for God to create a machine which ſhould be always in harmony with the operations of my ſoul; but it appears to me that my body belongs to me by other rights than ſuch a harmony, however beautiful it may be: and, I believe, you will not be diſpoſed haſtily to adopt a ſyſtem which is founded on this principle alone, that no ſpirit can act upon a body; and that, reciprocally, a body cannot act upon, or ſupply ideas to, a ſpirit. This principle is, beſides, deſtitute of all proof, the chimeras of it's partiſans, reſpecting ſimple beings, having been completely refuted. And if God, who is a ſpirit, has the power of acting upon bodies, it is not abſolutely impoſſible that a ſpirit, ſuch as the human ſoul, ſhould be able likewiſe to act upon a body. Accordingly, we do not pretend to ſay, that our ſoul acts upon all bodies, but only upon a ſmall particle of matter, with respect to which it has received the power of God himself, though to exercise it in a manner which we are utterly unable to comprehend.

Farther, the system of pre-established harmony labours under other great difficulties. According to it the soul derives all it's knowledge from it's own proper fund, without any contribution on the part of the body and the senses. Thus, when I read in the Gazette that the Pope is dead, and I come to the knowledge of the Pope's death, the Gazette and my reading have nothing to do with the communication of this knowledge, as these circumstances respect only my body and my senses, which have no manner of connection with my soul. But, conformably to this system, my soul derives, at the same time, from it's own proper fund, the ideas which it has of this same Pope. It concludes, he must absolutely be dead, and this knowledge comes to it with the reading of the Gazette, so that I imagine the reading of the Gazette furnished me with this knowledge, though I really derived it from the proper fund of my soul.

But this idea is perfectly absurd. How was it possible for me so boldly to assert, that the Pope must necessarily have died at the moment mentioned in the Gazette, and that, only from the idea which I had of the Pope's condition and health, though, perhaps, I knew nothing about him, while I am infinitely better acquainted with my own situation, without knowing, however, what shall befall me to-morrow.

In like manner when you do me the honour to read

read theſe letters, and derive the knowledge of ſome truth from them, it is your ſoul which extracts that truth from it's own proper fund, without my contributing at all to it by my letters. The reading of them ſerves only to maintain the harmony which the Creator meant to eſtabliſh between the ſoul and the body. It is only a formality, altogether ſuperfluous, with reſpect to the knowledge itſelf. I ſhall, nevertheleſs, continue to tender you my inſtructions.

9th December, 1760.

LETTER LXXXIV.

Another Objection.

THERE is another objection to be made to the ſyſtem of pre-eſtabliſhed harmony; namely, that it is utterly deſtructive of human liberty. In fact, if the bodies of men are machines, ſimilar to a watch, all their actions are a neceſſary conſequence of their conſtruction. Thus, when a thief ſteals my purſe, the motion made by his hands is an effect as neceſſary of the machine of his body, as the motion of the hand of my clock, now pointing to nine. You will readily comprehend what muſt be the concluſion. As it would be unjuſt, nay, ridiculous, to think of being angry at the clock, and of chaſtiſing it, becauſe it pointed to nine, it would be equally ſo, with reſpect to the thief, whom it would be abſurd to puniſh for having ſtolen my purſe.

 Of

Of this we had a well-known example in the reign of his late Majeſty, when Mr. *Wolff* taught at Halle the ſyſtem of the pre-eſtabliſhed harmony. The King informed himſelf of this doctrine, which was then making a prodigious noiſe; and one of his Court having ſuggeſted to him that, according to Mr. *Wolff's* doctrines, ſoldiers were mere machines, and that when one deſerted, it was a neceſſary conſequence of his particular ſtructure, and therefore ought not to ſubject him to puniſhment, as would be the caſe, were a machine an object of puniſhment, for having performed ſuch and ſuch a motion; the King was ſo provoked at this repreſentation, that he gave orders to baniſh *Wolff* from Halle, with certification, that if he was found there at the end of twenty-four hours, he ſhould be hanged up. The philoſopher upon this took refuge at Marburg, where I converſed with him ſoon after.

But the partiſans of this ſyſtem have always maintained that the pre-eſtabliſhed harmony by no means encroached on human liberty. They admit that the exterior actions of men are neceſſary effects of the organization of the body, and that, in this reſpect, they take place as neceſſarily as the motions of a watch: but that the mental determination enjoyed perfect liberty: that theſe may be deſerving of puniſhment, though the corporeal action was neceſſary: the criminality of an action conſiſts leſs in the motions of the body, than in the reſolution tion of the ſoul, which remains entirely free. onceive, ſay they, the ſoul of a thief, determining

mining, at a certain time, to commit a robbery: God having foreseen this intention, has provided it with a body, organized in such a manner as to produce, precisely at the same time, the motions requisite for the commission of this robbery: the action, say they, is itself the necessary effect of the organization of the body, but that the intention of the thief is a free act of his soul, which is not, on that account, less culpable and less punishable.

Notwithstanding this reasoning, the supporters of the system of pre-established harmony will always find themselves very much embarrassed to maintain the liberty of the determinations of the soul. For, according to them, the soul is itself similar to a machine, though of a nature totally different from that of the body; the representations produced in it are occasioned by those which precede, and these again by others anterior to them, and so on, so that they follow each other as necessarily as the motions of a machine. In fact, say they, men act always from certain motives, founded on the representations of the soul, which succeed each other, conformably to it's state.

You will recollect that, according to this system, the soul derives no one idea from the body, not being in any real connection with it; but all from it's own proper fund. Present ideas flow from those which preceded, and are a necessary consequence of them; so that the soul is nothing less than master of it's own ideas, which generate it's resolutions, and which are therefore as little under it's power: and,

 conseand this is directly oppofite to all that paffes in body. Would it not, then, be ridiculous to expect that a watch fhould point to any other hour than what it actually does, and to think of punifhing it on that account? Would it not be abfurd to fly into a paffion at a puppet, becaufe, after feveral other geftures, it had turned it's back to us?

All the changes which take place in bodies, and which are all reducible to their ftate of reft, or of motion, are the neceffary confequence of the powers which act upon them; and their action once admitted, no changes in bodies can take place, but precifely fuch as do take place: what refpects body, therefore, is an object of neither praife nor blame. However ingenioufly a piece of mechanifm may be conftructed, the commendation which we beftow upon it reverts to the artift; the machine itfelf has no intereft in what paffes; the artift, too, is alone refponfible for the defects of a clumfy and aukward machine; the machine itfelf is perfectly innocent. While, therefore, the enquiry is reftricted to bodies, they are clearly in no refpect refponfible; no reward, no punifhment can poffibly attach to them; all the changes and motions produced in them, are the neceffary confequences of their ftructure.

But fpirits are of a very different nature, and their ...ons depend on principles directly oppofite. Li...y, entirely excluded from the nature of body, is ...fential portion of fpirit, to fuch a degree, that ...out liberty, a fpirit could not exift; and this it ...h renders it refponfible for it's actions. This

property

property is as essential to spirit as extension or impenetrability is to body; and as it would be impossible for the divine Omnipotence itself to divest body of these qualities, it would be equally impossible for it to divest spirits of liberty. A spirit without liberty, would no longer be a spirit, as a body without extension would no longer be a body.

It has in all ages been a subject of eager enquiry among philosophers, How God could have permitted sin to enter into the world? Had they reflected that the souls of men are beings necessarily free, from their very nature, the controversy would have been easily settled.

The objections commonly made to human liberty are these: A spirit, it is said, or a man, is never determined to an action, but from motives; and after having carefully weighed the reasons on both sides, he finally decides in favour of that which he deems the preferable. Hence they conclude that motives determine the actions of men, just as the motion of a ball on the billiard table is determined by the stroke impressed upon it, and that the actions of men are no more free than the motion of the ball. But it must be considered that the motives which engage a man to undertake any enterprize, refer very differently to the soul, from what the stroke does to the ball. The stroke produces it's effect necessarily; but a motive, however powerful, prevents not the action from being voluntary. I had very powerful motives to undertake a journey to Magdeburg: a regard to my promise; the prospect of enjoying the felicity of paying my refpects to your Highnefs; but I am perfectly fenfible, at the fame time, that I was not forced to it: and that it was entirely in my own power to take that journey, or to have remained at Berlin. But a body, impelled by any power, neceffarily obeys, and it cannot be affirmed that it was at liberty to obey, or not, as it pleafed.

The motive which determines a fpirit to regulate it's refolves, is of a nature wholly different from a *caufe* or *force* acting upon body. Here, the effect is produced neceffarily; and there, the effect remains always voluntary, and the foul has power over it. On this is founded the *imputability* of the actions of a fpirit, which makes it refponfible for them, and which is the true foundation of right and wrong. As foon as we have fettled this infinite difference between fpirit and body, the queftion refpecting liberty prefents very little difficulty.

16th *December*, 1760.

LETTER LXXXVI.

The fame Subject continued.

THE difference which I have just eftablifhed between the *motives*, conformably to which fpirits [illegible] *caufes* or *powers* which act on bodies [illegible] the true foundation of liberty. [illegible] puppet fo artfully conftructed [illegible] [illegible]ings, as to be capable to approach [illegible] pocket, and to pick out my watch, without my perceiving it. This action being a neceſſary conſequence of the organization of the machine, could not be conſidered as a robbery; and I ſhould render myſelf ridiculous if I got into a paſſion at it, and inſiſted on having the machine hanged. Every one would ſay that the puppet was innocent, and incapable of committing a blameable action; it would be, beſides, equally indifferent to the puppet to be hanged, or placed on a throne. But if the artiſt had contrived this machine on purpoſe to ſteal, and to enrich himſelf by ſuch means, however much I might admire the ingenuity diſplayed on the mechaniſm, I ſhould reckon myſelf obliged to bring him to juſtice as a thief. It follows, then, that even in this caſe the criminality reverts upon an intelligent being, or a ſpirit, and that ſpirits alone are reſponſible for their actions.

Let every man examine his own actions, and he will always find that he was not forced into them, though he might be induced by motives. If his actions are commendable, he is perfectly conſcious of meriting the praiſes beſtowed upon him. However he might be deceived in his other judgments, he cannot in this caſe; the ſentiment of his liberty is ſo intimately connected with that liberty itſelf, that they are inſeparable. It is poſſible to entertain a doubt where the liberty of another is concerned, but it is impoſſible ever to be deceived reſpecting one's own. A clown, for example, on ſeeing the puppet above deſcribed, might eaſily imagine it to be a real thief,

thief, and that it likewiſe was a free agent: in this he would be miſtaken; but with reſpect to his own liberty, it is impoſſible for him to miſtake; as he deems himſelf free, he is ſo in fact. It might likewiſe happen, that the clown in queſtion, undeceived as to the puppet, ſhould afterwards conſider a dexterous thief as a machine, deſtitute of all ſentiment, and of liberty: here he would fall into the oppoſite error, but as to his own actions, he will never be miſtaken.

It would, therefore, be ridiculous to affirm, that it might be poſſible for a watch to imagine that it's hand turned freely, and to believe that it now points to nine, becauſe it pleaſes to do ſo, but could point to any other hour, if it thought proper: the watch would undoubtedly deceive itſelf. But the whole ſuppoſition is manifeſtly abſurd. You muſt firſt aſcribe to the watch ſentiment and imagination, and accordingly ſuppoſe it a ſpirit or ſoul, which neceſſarily implies liberty; and afterwards conſider it as a mere machine, diveſted of liberty, which is a manifeſt contradiction.

Another objection, however, is ſtarted againſt liberty, founded on the divine *preſcience*. God, it is ſaid, foreſaw, from all eternity, every reſolution which I ſhould form, and every action which I ſhould
every inſtant of my life. If God foreſaw
t I now continue to write, that I ſhould,
lay down my pen, and riſe to take a
on would be no longer free, for I am
eſſity of writing, of laying down the
pen,

pen, and of rising to walk; and it would be impossible for me to act otherwise, as it was impossible God should be deceived in what he foresees?

The reply is obvious. Because God foresaw, from all eternity, that I should perform, on such a day, such an action, it does not follow that I shall perform it, because God foresaw it. For it is evident that it ought not to be alleged, in the cause supposed, That I go on to write, *because* God foresaw I should go on to write; but, on the contrary, as I judge it proper to go on to write, God foresaw that I would do so. Thus the prescience of God by no means encroaches on my liberty; and all my actions remain equally at liberty, whether God foresaw them or not.

Some, however, in the view of supporting liberty, have gone so far as to deny the divine prescience; but you will have little difficulty in detecting the falsehood of this opinion. Is it so surprising that the Supreme Being, who is acquainted with all my propensities, should be able to foresee the effect which every motive will produce on my soul, and, consequently, all the resolutions which I shall form, in conformity to these effects, when simple mortals, such as we are, frequently exercise a similar prescience? You can easily imagine to yourself a man extremely covetous, who has a fair opportunity of making a considerable advantage. You know, for certain, he will not fail to avail himself of it. Your knowledge of this, however, has no influence upon the man; he goes into it with the full determination of his own mind, as if you had never spent a thought upon him.

him. Now, as God is infinitely better acquainted with men, and all their dispositions, it is not to be doubted that he could have foreseen their actions, in all situations. The prescience of God, with respect to the free actions of spirits, is, nevertheless, founded on another principle than that of the changes which *must* take place in the corporeal world, where all is under the power of necessity. This distinction shall be the subject of my next letter.

20th December, 1760.

LETTER LXXXVII.

Influence of the Liberty of Spirits upon Events.

IF the world contained bodies only, and if the changes which take place in it, were necessary consequences of the laws of motion, conformably to the powers with which they act upon each other, all events would be necessary, and would depend on the first arrangement which the Creator had established of the bodies of the universe; so that this arrangement, once established, it should be impossible for other events afterwards to take place, than those which happen in the actual order of things. The world would, undoubtedly, be in this case, a mere machine, similar to a watch, which, once wound up, afterwards produces all the motions by which we measure time.

Imagine to yourself a musical clock; such a clock, once regulated, all the motions which it performs, and

and the airs which it plays, are produced in virtue of it's conſtruction, without any freſh application of the hand of the maſter, and, in that caſe, we ſay it is done mechanically. If the artiſt touches it, by changing the notch, or the cylinder, which regulates the airs, or by winding it up, it is an external action, which, not being founded on the organization of the machine, no longer appertains to it. And if God, as Lord of the univerſe, ſhould change immediately any thing in the courſe of ſucceſſive events, this change would no longer appertain to the machine: it would then be a *miracle*.

A miracle, conſequently, is an immediate effect of the divine Omnipotence, which could not have taken place, had God left the machine of the univerſe freely to take it's courſe. Such would be the ſtate of the univerſe, if it contained bodies only; in that caſe it might be ſaid, that all events take place in it from an abſolute neceſſity, each of them being a neceſſary effect of the ſtructure of the univerſe; unleſs it pleaſed God to work miracles.

The ſame thing would happen, on admitting the ſyſtem of pre-eſtabliſhed harmony, though it allows the exiſtence of ſpirits; for, according to this ſyſtem, ſpirits do not act upon bodies, but theſe perform all their motions and actions only in virtue of their ſtructure, once eſtabliſhed; ſo that when I raiſe my arm, this motion is an effect as neceſſary of the organization of my body, as that of the wheels in a watch. My ſoul, in no reſpect, contributes to it; it is God who, from the beginning, arranged the matter, so that the action of my body must necessarily result from it, at a certain time, and raise the arm at the instant that my soul willed it. Thus, my soul has no influence upon my body, any more than upon those of other men and of animals: and, consequently, according to this system, the universe is merely corporeal, and events are a necessary effect of the primitive organization which God has established in the universe.

But, if we allow to the souls of men and of animals the power of producing motion in their bodies, which their organization alone would not have produced, the system of the universe is not a mere machine, and events do not necessarily take place as in the preceding case.

The universe will present events of two kinds; the one, those over which spirits have no manner of influence, which are corporeal, or dependant on the machine, as the motion and phenomena of the heavenly bodies; these take place as necessarily as those of a watch, and depend entirely on the primitive establishment of the universe. The others depend on the soul, united to the body of men and animals, and are no longer necessary, as the preceding, but result from the liberty, as from the will, of these spiritual beings.

These two kinds of events distinguish the universe from a mere machine, and raise it to a rank infinitely more worthy of the almighty Creator, who formed it.

it. The government of this univerſe will likewiſe ever inſpire us with the moſt ſublime idea of the ſovereign wiſdom and goodneſs of God.

It is certain, therefore, that liberty, which is abſolutely eſſential to ſpirits, has a very great influence on the events of the world. You have only to conſider the fatal conſequences of theſe wars, which all reſult from human actions, determined by their will, or their caprice.

It is likewiſe certain, at the ſame time, that the events which take place do not depend only on the will of men and animals. Their power is very limited, being reſtricted to a ſmall portion of the brain, in which all the nerves terminate: and this action is confined to the communication of an impreſſion of a certain motion on the members, which may afterwards operate on other bodies, and theſe again on others, ſo that the ſlighteſt motion of my body may have a very great influence on a multitude of events.

Man, however, though maſter of the firſt motion of his body, which occaſions theſe events, is not ſo of the conſequences of his action. Theſe depend on ſo many circumſtances, that the moſt ſagacious mind is incapable of foreſeeing them: accordingly, we every day ſee the beſt concerted projects failing. But it is here that we muſt acknowledge the government and providence of God, who, having from all eternity foreſeen all the counſels, the projects, and the voluntary actions of men, arranged the corporeal world in ſuch a manner, that it brings about, at all times, circumſtances which cauſe theſe enterprizes to fail

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A ſtructure equally marvellous is obſervable in all the other parts of our bodies, in thoſe of all animals, and even of the vileſt inſects. And the ſtructure of theſe laſt, is ſo much the more admirable, on account of their ſmallneſs, that it ſhould perfectly ſatisfy all the wants which are peculiar to each ſpecies. Let us examine only the ſenſe of ſeeing in theſe inſects, by which they diſtinguiſh objects ſo minute, and ſo near, as to eſcape our eyes, and this examination alone will fill us with aſtoniſhment.

We diſcover the ſame perfection in plants: every thing in them concurs to their formation, to their growth, and to the production of their flowers, of their fruits, or of their ſeeds. What a prodigy to behold a plant, a tree, ſpring from a ſmall grain, caſt into the earth, by the help of the nutritious juices with which the ſoil ſupplies it? The productions found in the bowels of the earth are no leſs wonderful: every part of nature is capable of exhauſting our utmoſt powers of reſearch, without permitting us to penetrate all the wonders of it's conſtruction. Nay, we are utterly loſt, while we reflect, how every ſubſtance, earth, water, air, and fire, concur in the production of all organized bodies; and, finally, how the arragement of all the heavenly bodies is ſo admirably contrived, as perfectly to fulfil all theſe particular deſtinations.

After having reflected in this manner, it will be difficult for you to believe, that there ſhould have been men who maintained, that the univerſe was the fail or to ſucceed, according as his infinite wiſdom judges to be moſt fit. God thus remains abſolute ſovereign of all events, notwithſtanding the liberty of men, all whoſe actions, though free, are, from the beginning, part of the plan which God intended to execute, when he created this univerſe.

This reflection plunges us into an abyſs of wonder and adoration at the infinite perfections of the Creator; while we conſider that there is nothing ſo mean in itſelf as not to be, from the beginning of the world, an object worthy of entering into the original plan which God propoſed to himſelf.

23d December, 1760.

LETTER LXXXVIII.

Of Events, natural, ſupernatural, and moral.

IN common life, we carefully diſtinguiſh events produced by corporeal cauſes from thoſe in which men and animals co-operate. Thoſe of the former deſcription are denominated *natural events*, or produced by natural cauſes; ſuch are the phenomena of the heavenly bodies, eclipſes, tempeſts, whirlwinds, earthquakes, &c. Theſe are called natural phenomena, becauſe it is underſtood that neither men nor animals are active in the production of them.

If we ſee a tree torn up by the roots, through the violence of the wind, we call it a natural effect: but if it were done by the ſtrength of man, or the pro-

boſcis

A ſtructure equally marvellous is obſervable in all the other parts of our bodies, in thoſe of all animals, and even of the vileſt inſects. And the ſtructure of theſe laſt, is ſo much the more admirable, on account of their ſmallneſs, that it ſhould perfectly ſatisfy all the wants which are peculiar to each ſpecies. Let us examine only the ſenſe of ſeeing in theſe inſects, by which they diſtinguiſh objects ſo minute, and ſo near, as to eſcape our eyes, and this examination alone will fill us with aſtoniſhment.

We diſcover the ſame perfection in plants: every thing in them concurs to their formation, to their growth, and to the production of their flowers, of their fruits, or of their ſeeds. What a prodigy to behold a plant, a tree, ſpring from a ſmall grain, caſt into the earth, by the help of the nutritious juices with which the ſoil ſupplies it? The productions found in the bowels of the earth are no leſs wonderful: every part of nature is capable of exhauſting our utmoſt powers of reſearch, without permitting us to penetrate all the wonders of it's conſtruction. Nay, we are utterly loſt, while we reflect, how every ſubſtance, earth, water, air, and fire, concur in the production of all organized bodies; and, finally, how the arragement of all the heavenly bodies is ſo admirably contrived, as perfectly to fulfil all theſe particular deſtinations.

After having reflected in this manner, it will be difficult for you to believe, that there ſhould have been men who maintained, that the univerſe was the effect of mere chance, without any design. But there always have been, and there still are, persons of this description; those, however, who have a solid knowledge of nature, and whom fear of the justice of God does not prevent from acknowledging Him, are convinced, with us, that there is a Supreme Being, who created the whole universe, and, from the remarks which I have just been suggesting to you, respecting bodies, every thing has been created in the highest perfection.

As to spirits, the wickedness of man seems to be an infringement of this perfection, as it is but too capable of introducing the greatest evils into the world, and these evils have, at all times, appeared incompatible with the sovereign goodness of God. This is the weapon usually employed by infidels against religion, and the existence of God. If God, say they, was the author of the world, He must also be the author of the evil which it contains, and of the crimes committed in it.

This question, respecting the origin of evil; the difficulty of explaining, How it can consist with the sovereign goodness of God, has always greatly perplexed philosophers and divines. Some have endeavoured to give a solution, but it has satisfied only themselves. Others have gone so far as to maintain, that God was, in fact, the author of moral evil, and of crimes; always protesting, at the same time, that this opinion ought to bring no imputation on the goodness and holiness of God. Others, finally, consider

ſider this queſtion as a myſtery which we cannot comprehend; and theſe laſt, undoubtedly, have embraced the preferable ſentiment.

God is ſupremely good and holy; He is the author of the world, and that world ſwarms with crimes and calamities. Theſe are three truths which it is, apparently, difficult to reconcile: but, in my opinion, a great part of the difficulty vaniſhes, as ſoon as we have formed a juſt idea of ſpirit, and of the liberty ſo eſſential to it, that God himſelf cannot diveſt it of this quality.

God having created ſpirits, and the ſouls of men, I remark, firſt, that ſpirits are beings infinitely more excellent than bodies; and, ſecondly, that, at the moment of creation, ſpirits were all good: for time is requiſite to the formation of evil inclinations: there is, therefore, no difficulty in affirming, that God created ſpirits. But it being the eſſence of ſpirits to be free, and liberty not being capable of ſubſiſting without a power to ſin, to create a ſpirit poſſeſſed of the power of ſinning, has nothing inconſiſtent with divine perfection, becauſe a ſpirit could not be created deſtitute of that power.

God has, beſides, done every thing to prevent crimes, by preſcribing to ſpirits, precepts, the obſervance of which muſt always render them good and happy. There is no other method of treating ſpirits, which cannot be ſubject to any conſtraint; and if ſome of them have abuſed their liberty, and tranſgreſſed theſe commandments, they are reſponfible for it, and worthy of punifhment, without any impeachment of the Deity.

There remains only one objection more to be confidered: namely, that it would have been better not to create fuch fpirits, as God forefaw they muft fink into criminality. But this far furpaffes human underftanding; for we know not, whether the plan of the world could fubfift without them. We know, on the contrary, by experience, that the wickednefs of fome men frequently contributes to the correction and amendment of others, and thereby conducts them to happinefs. This confideration, alone, is fufficient to juftify the exiftence of evil fpirits. And, as God has all power over the confequences of human wickednefs, every one may reft affured, that in conforming to the commandments of God, all events which come to pafs, however calamitous they may appear to him, are always under the direction of Providence, and, finally, terminate in his true happinefs.

This providence of God, which extends to every individual, in particular, thus furnifhes the moft fatisfactory folution of the queftion refpecting the permiffion, and the origin, of evil.*

30th December, 1760.

* Mr. *Euler* concludes this letter, with the following fhort fentence: " This likewife is the foundation of all religion, the alone " object of which is to promote the falvation of mankind." What reafon could there be for fuppreffing a fentiment fo natural, fo much in place, and fo inoffenfive?—*E. E.*

LETTER

LETTER XC.

Connection of the preceding Considerations with Religion. Reply to the Objections of the philosophic Systems against Prayer.

BEFORE I proceed farther in my lessons on philosophy and physics, I think it my duty to point out to you their connection with religion.*

I begin with considering an objection, which almost all the philosophic systems have started, against prayer. Religion prescribes this as our duty, with an assurance, that God will hear and answer our vows and prayers, provided they are conformable to the precepts which he has given us. Philosophy, on the other hand, instructs us, that all events take place in strict conformity to the course of nature, established

* I take the liberty, likewise, to restore the following passage, which M. *de Condorcet*, in his philosophic squeamishness, has thought unworthy of a place in his edition of the work.

"However extravagant and absurd the sentiments of certain "philosophers may be, they are so obstinately prepossessed in favour of them, that they reject every religious opinion and doctrine, which is not conformable to their system of philosophy. "From this source are derived most of the sects and heresies in religion. Several philosophic systems are really contradictory to "religion; but in that case, divine truth ought, surely to be preferred to the reveries of men, if the pride of philosophers knew "what it was to yield. Should sound philosophy sometimes seem "in opposition to religion, that opposition is more apparent than "real; and we must not suffer ourselves to be dazzled with the "speciousness of objection."—*E. E.*

liſhed from the beginning, and that our prayers can effect no change whatever; unleſs we pretend to expect, that God ſhould be continually working miracles, in compliance with our prayers. This objection has the greater weight, that religion itſelf teaches the doctrine of God's having eſtabliſhed the courſe of all events, and that nothing can come to paſs, but what God foreſaw from all eternity. Is it credible, ſay the objectors, that God ſhould think of altering this ſettled courſe, in compliance with any prayers which men might addreſs to him?

But I remark, firſt, that when God eſtabliſhed the courſe of the univerſe, and arranged all the events which muſt come to paſs in it, he paid attention to all the circumſtances which ſhould accompany each event; and particularly to the diſpoſitions, to the deſires, and prayers, of every intelligent being; and that the arrangement of all events was diſpoſed, in perfect harmony, with all theſe circumſtances. When, therefore, a man addreſſes to God a prayer worthy of being heard, it muſt not be imagined, that ſuch a prayer came not to the knowledge of God till the moment it was formed. That prayer was already heard from all eternity; and if the Father of mercies deemed it worthy of being anſwered, He arranged the world expreſsly in favour of that prayer, ſo that the accompliſhment ſhould be a conſequence of the natural courſe of events. It is thus that God anſwers the prayers of men, without working a miracle.

The eſtabliſhment of the courſe of the univerſe, fixed

fixed once for all, far from rendering prayer unnecessary, rather increases our confidence, by conveying to us this consolatory truth, That all our prayers have been already, from the beginning, presented at the feet of the throne of the Almighty, and that they have been admitted into the plan of the universe, as motives conformably to which events were to be regulated, in subserviency to the infinite wisdom of the Creator.

Can any one believe, that our condition would be better, if God had no knowledge of our prayers before we presented them, and that He should then be disposed to change, in our favour, the order of the course of nature? This might well be irreconcileable to his wisdom, and inconsistent with his adorable perfections. Would there not, then, be reason to say, that the world was a very imperfect work? that God was entirely disposed to be favourable to the wishes of men; but, not having foreseen them, was reduced to the necessity of, every instant, interrupting the course of nature, unless he were determined totally to disregard the wants of intelligent beings, which, nevertheless, constitute the principal part of the universe? For to what purpose create this material world, replenished with so many great wonders, if there were no intelligent beings, capable of admiring it, and of being elevated by it, to the adoration of God, and to the most intimate union with their Creator, in which, undoubtedly, their highest felicity consists?

Hence, it must, absolutely, be concluded, that intelligent

telligent beings, and their salvation, must have been the principal object, in subordination to which, God regulated the arrangement of this world; and we have every reason to rest assured, that all the events which take place in it, are in the most delightful harmony with the wants of all intelligent beings, to conduct them to their true happiness; but without constraint, because of their liberty, which is as essential to spirits, as extension is to body. There is, therefore, no ground for surprize, that there should be intelligent beings, which shall never reach felicity.

In this connection, of spirits with events, consists the divine Providence, of which every individual has the consolation of being a partaker; so that every man may rest assured, that, from all eternity, he entered into the plan of the universe. How ought this consideration to increase our confidence, and our joy in the providence of God, on which all religion is founded! You see then, that on this side religion and philosophy are by no means at variance.

3d January, 1761.

LETTER XCI.

The Liberty of intelligent Beings in Harmony with the Doctrines of the Christian Religion.

LIBERTY is a quality so essential to every spiritual being, that God himself cannot divest them of it, just as He cannot divest a body of it's extension,

tension, or of it's *inertia*, without entirely destroying, or annihilating it: to divest a spirit of liberty, therefore, would be the same thing as to annihilate it. This must be understood of the spirit, or soul itself, and not of the actions of the body, which the soul directs, in conformity to it's will. If you would prevent me from writing, you have but to bind my hands; to write is, undoubtedly, an exercise of liberty; but then, though you may say, that you have deprived me of the liberty of writing, you have only deprived my body of the faculty of obeying the dictates of my soul. Bind me ever so hard, you cannot extinguish in my spirit an inclination to write; all you can do is to prevent the execution of it.

We must always carefully distinguish between inclination, or the act of willing, and execution, which is performed by the ministration of the body. The act of willing cannot be restrained by any exterior power, not even by that of God, for liberty is independent of all exterior force. But there are means of acting on spirits, by motives which have a tendency, not to constrain, but to persuade. Let a man be firmly determined to engage in any enterprize, and let us suppose the execution of it prevented; without making any change in his intention, or will, it might be possible to suggest motives, which should engage him to abandon his purpose, without employing any manner of constraint: however powerful these motives may be, he is always master of his own will; it never can be said, that he was forced, or constrained, to it, at least the expression divine Providence over-ruled that circumſtance, ſo ſalutary to him. In fact, without the opportunity, over which the man had no power, he would have perſiſted in a ſinful courſe.

Hence, you will eaſily comprehend the meaning of ſuch expreſſions as theſe: "Man can do nothing of "himſelf; all depends on divine grace; it is God "that worketh to will and to do." The favourable circumſtances which Providence ſupplies to men, are ſufficient to elucidate theſe expreſſions, without having recourſe to a ſecret force, which acts by conſtraint on human liberty; as theſe circumſtances are directed of God, in conformity to the moſt conſummate wiſdom, in the view of conducting every intelligent being to happineſs and ſalvation, unleſs he wilfully rejects the means by which he might have attained true felicity.

6th January, 1761.

LETTER XCII.

Elucidation reſpecting the Nature of Spirits.

IN order more clearly to elucidate what I have juſt ſaid reſpecting the difference between body and ſpirit; for it is impoſſible to be too attentive to what conſtitutes that difference, as it extends ſo far, that ſpirit has nothing in common with body, nor body with ſpirit, I think it neceſſary to ſubjoin the following reflections.

Extenſion,

Extenſion, *inertia* and impenetrability, are the properties of body; Spirit is without extenſion, without *inertia*, without impenetrability. All philoſophers are agreed, that extenſion cannot have place in reſpect of ſpirit. It is a ſelf-evident truth, for every thing extended is diviſible, and you can form the idea of it's parts; but a ſpirit is ſuſceptible of no diviſion; you can have no conception of it's half, or of it's third part. Every ſpirit is a complete being, to the excluſion of all parts; it cannot, then, be affirmed, that a ſpirit has length, breadth, or thickneſs. In a word, all that we conceive of extenſion, muſt be excluded from the idea of a ſpirit.

It would appear, therefore, that as ſpirits have no magnitude, they muſt reſemble geometrical points, the definition of which is, that they have neither length, breadth, nor depth. Would it be a very accurate idea to repreſent to ourſelves a ſpirit by a mathematical point? The ſcholaſtic philoſophers have profeſſed this opinion, and conſidered ſpirits as beings infinitely ſmall, ſimilar to the moſt ſubtile particles of duſt, but endowed with an inconceivable activity and agility, by which they are enabled to tranſport themſelves, in an inſtant, to the greateſt diſtances. They maintained, that in virtue of this extreme minuteneſs, millions of ſpirits might be incloſed in the ſmalleſt ſpace; they even made it a queſtion, How many ſpirits could dance on the point of a needle?

The diſciples of *Wolff* are nearly of the ſame opinion. According to them, all bodies are compoſed [illegible]articles extremely minute, diveſted of all magnitude,

tude, and they give them the name of monads. A monad, then, is a ſubſtance deſtitute of all extenſion, and on dividing a body, till you come to particles ſo minute, as to be ſuſceptible of no farther diviſion, you have got to the Wolfian monad, which differs, therefore, from the moſt ſubtile particle of duſt, only in this, that the minuteſt particles of duſt are not, perhaps, ſufficiently ſmall, and that a farther diviſion is ſtill neceſſary to obtain real monads.

Now, according to Mr. *Wolff*, not only all bodies are compoſed of monads, but every ſpirit is merely a monad; and the Supreme Being, I tremble as I write it, is, likewiſe, a monad. This does not convey a very magnificent idea of God, of ſpirits, and of the ſouls of men. I cannot conceive, that my ſoul is nothing more than a being, ſimilar to the laſt particles of a body, or that it is reduced almoſt to a point. It appears to me ſtill leſs capable of being maintained, that ſeveral ſouls joined together, might form a body, a ſlip of paper, for example, to light a pipe of tobacco. But the ſupporters of this opinion, go upon this ground, that as a ſpirit has no magnitude, it muſt, of neceſſity, reſemble a geometrical point. Let us examine the ſolidity of their reaſoning.

I remark, firſt, that as a ſpirit is a being of a nature totally different from that of body, it is abſurd to apply to it ſtandards, which ſuppoſe magnitude, and that, conſequently, it would be folly to aſk, how many feet, or inches, long, a ſpirit is, or how many pounds, or ounces, it weighs? Theſe queſtions are applicable only to things which have length, or weight: and are as abſurd as if, ſpeaking of time, it were to be aſked, how many feet long an hour was, or how many pounds it weighed? I can always, confidently, affirm, that an hour is not equal to a line of 100 feet, or of ten feet, or of one foot, or any other ſtandard of meaſure; but it by no means follows, that an hour muſt be a geometrical point. An hour is of a nature entirely different, and it is impoſſible to apply to it any ſtandard, which ſuppoſes a length, which may be expreſſed by feet, or inches.

The ſame thing holds good as to ſpirit. I can always boldly affirm, that a ſpirit is not ten feet, nor 100 feet, nor any other number of feet; but it does not hence follow, that a ſpirit is a point, any more than that an hour muſt be one, becauſe it cannot be meaſured by feet or inches. A ſpirit, then, is not a monad, or in any reſpect ſimilar to the ultimate particles into which bodies may be divided; and you are perfectly able to comprehend, that a ſpirit may have no extenſion, without being, on that account, a point, or a monad. We muſt, therefore, ſeparate every idea of extenſion from that of ſpirit.

To aſk, In what place does a ſpirit reſide? would be, for the ſame reaſon, likewiſe, an abſurd queſtion; for to connect ſpirit with place, is to aſcribe extenſion to it. No more can I ſay, in what place an *hour* is; though aſſuredly an hour is ſomething; ſomething, therefore, may exiſt, without being attached to a certain place. I can, in like manner, affirm, that my ſoul does not reſide in my head, nor out of my head, nor in any particular place; without it's

being

being deduced, as a consequence, that my ſoul has, therefore, no exiſtence; juſt as it may be with truth affirmed of the hour now paſſing, that it exiſts nei- in my head, nor out of my head. A ſpirit exiſts, then, though not in a certain place; but if our reflection turns on the power which a ſpirit has, of acting upon a body, the action is, moſt undoubtedly, performed in a certain place.

My ſoul, then, does not exiſt in a particular place, but it acts there, and as God poſſeſſes the power of acting upon all bodies, it is, in this reſpect, we ſay, He is every where, though his exiſtence is attached to no place.

10th January, 1761.

LETTER XCIII.

The Subject continued. Reflections on the State of Souls after Death.

YOU will, probably, be ſurprized at the ſentiment which I have juſt now ventured to advance, that ſpirits, in virtue of their nature, are in no place. In thus affirming, I ſhall, perhaps, be in danger of paſſing for a man who denies the exiſtence of ſpirits, and, conſequently, that of God. But I have already demonſtrated, that ſomething may exiſt, and have a reality, without being attached to any one place. The example drawn from an hour, though feeble, removes the greateſt difficulties, though there is an infinite difference between an hour and a ſpirit.

The idea which I form of ſpirits, appears to me incomparably more noble than that of thoſe who conſider them as geometrical points, and who reduce God himſelf to this claſs. What can be more ſhocking than to confound all ſpirits, and the Supreme Being among the reſt, with the minuteſt particles into which a body is diviſible, and to rank them in the ſame claſs with theſe particles, which it is not in the power of the learned term monad to ennoble?

To be in a certain place, is an attribute belonging only to corporeal things, and, as ſpirits are of a totally different nature, it is not a matter of ſurprize to ſay, that they are not to be found in any place, and I am under no apprehenſion of reproach, for the elucidations which I have ſubmitted to you on this ſubject. It is thus I exalt the nature of ſpirits infinitely above that of bodies.

Every ſpirit is a being that thinks, reflects, reaſons, deliberates, acts freely, and, in one word, that lives: whereas body has no other qualities but that of being extended, ſuſceptible of motion, and impenetrable; from whence reſults this univerſal quality, that every body remains in the ſame ſtate, as long as there [illegible] ceſſity of mutual penetration, or of [illegible] ſome change; and in caſe of the [illegible] penetrating each other, if they con[illegible] in their ſtate, their impenetrability [illegible] the powers requiſite to change their ſtate,

ſtate, as far as it is neceſſary to prevent all penetration.

In this conſiſt all the changes which take place in bodies: all is paſſive, and neceſſarily befalls them in conformity to the laws of motion. There is, in body, neither intelligence, nor will, nor liberty: theſe are the ſupereminent qualities of ſpirits, while bodies are not even ſuſceptible of them.

It is ſpirit, likewiſe, which produces, in the corporeal world, the principal events, the illuſtrious actions, of intelligent beings, which are all the effect of the influence which the ſouls of men exerciſe upon their bodies. This power, which every ſoul has over it's body, cannot but be conſidered as a gift of God, who has eſtabliſhed this wonderful union between ſoul and body. And as I find my ſoul in ſuch an union with a certain particle of my body, concealed in the brain, it may be ſaid, that the ſeat of my ſoul is in that ſpot, though, properly ſpeaking, my ſoul reſides no where, and is referable to that place of my body, only in virtue of it's action, and of it's power.

It is alſo the influence of the ſoul upon the body which conſtitutes it's life, which continues as long as this uniſon ſubſiſts, or as the organization of the body remains entire. Death, then, is nothing elſe but the diſſolution of this union, and the ſoul has no need to be tranſported elſewhere; for, as it reſides in no place, all places muſt be indifferent to it; and, conſequently, if it ſhould pleaſe God, after my death, to eſtabliſh a new union between my ſoul, and an organized body in the moon, I ſhould inſtantly be in the moon, without the trouble of a long journey. And if, even now, God were to grant to my ſoul, a power over an organized body in the moon, I ſhould be equally here, and in the moon; and this involves no manner of contradiction. It is body only which cannot be in two places at once; but there is nothing to prevent ſpirit, which has no relation to place, in virtue of it's nature, to act at the ſame time, on ſeveral bodies, ſituated in places very remote from each other; and, in this reſpect, it might be ſaid, with truth, that it was in all theſe places at once.

This ſupplies us with a clear elucidation of the omnipreſence of God: it is, that his power extends to the whole univerſe, and to all the bodies which it contains. It appears to me, of conſequence, an improper expreſſion, to ſay, that God exiſts every where, as the exiſtence of a ſpirit has no relation to place. It is more conſonant with propriety to ſay, God is every where preſent.

Let us now compare this idea with that of the Wolfians, who, repreſenting Deity under the idea of a point, attach him to one fixed place, as, in fact, a point cannot be in ſeveral places at once; and how
poſſible to reconcile the divine omnipotence,
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s the ſoul, during life, derives all it's know-
ledge

ledge through the medium of the ſenſes, being deprived, by death, of the information communicated through the ſenſes, it no longer knows what is paſſing in the material world; this ſtate might, in ſome reſpects, be compared to that of a man who ſhould, all at once, become blind, deaf, dumb, and deprived of the uſe of all the other ſenſes. Such a man would retain the knowledge which he had acquired, through the medium of ſenſe, and might continue to reflect on ideas previouſly formed; his own actions, eſpecially, might ſupply an ample ſtore, and, finally, the faculty of reaſoning might remain entire, as the body, in no reſpect whatever contributes to it's exerciſe.

Sleep, likewiſe, furniſhes us with ſomething like an example of this ſtate, as the union between ſoul and body is then, in a great meaſure, interrupted; though the ſoul, even in ſleep, ceaſes not from exerting it's activity, being employed in the production of what we call dreams. Theſe dreams are uſually very much diſturbed, by the remains of the influence which the ſenſes ſtill exerciſe over the ſoul; and we know, by experience, that the more this influence is ſuſpended, which is the caſe in very profound ſleep, the more regular and connected, likewiſe, our dreams are. Thus, after death, we ſhall find ourſelves in a more perfect ſtate of dreaming, which nothing ſhall be able to diſcompoſe: it ſhall conſiſt of repreſentations, and reaſonings, perfectly well kept up. And this, in my opinion, is nearly all we can ſay of it, at leaſt, with any appearance of reaſon.

13th Jan. 1761.

LETTER XCIV.

Conſiderations on the Action of the Soul upon the Body, and of the Body upon the Soul.

AS the ſoul is the principal part of our being, it is of high importance, thoroughly to inveſtigate it's operations. You will pleaſe to recollect, that the union between the ſoul and the body, contains a two-fold influence: by the one, the ſoul perceives and feels all that paſſes in a certain part of the brain; and by the other, it has the power of acting on that ſame portion of the brain, and of producing certain motions in it.

Anatomiſts have taken infinite pains to diſcover this part of the brain, which is juſtly called the ſeat of the ſoul; not that the ſoul actually reſides there, for it is not confined to any place, but becauſe the power of acting is attached to that ſpot. It may be ſaid, that the ſoul is preſent there, but not that it exiſts there, or that it's exiſtence is limited to it. This part of the brain is, undoubtedly, that in which all the nerves terminate; now, anatomiſts tell us, that this termination is in a certain portion of the
...which they term the *callous body*. This, there-
...ſider as the ſeat of the ſoul, and the
...owed, upon every ſoul, ſuch a power
...membrane * of his body, that it not

* ...have given us a more exact and particular de-
...m, we have been obliged to relinquiſh this
opinion;

only perceives all that paſſes there, but is, likewiſe, able to produce a reciprocal impreſſion. Here, then, we obſerve a two-fold action: the one, by which the body acts upon the ſoul, and the other, by which the ſoul acts upon the body, but theſe actions are infinitely different from thoſe which bodies exerciſe upon other bodies.

The ſoul, from it's union with the *corpus calloſum*, finds itſelf intimately connected with the whole body, by means of the nerves, which are thence univerſally diffuſed. Now, the nerves are fibres ſo wonderfully conſtructed, and, to all appearance, filled with a fluid ſo ſubtile, that the ſlighteſt change which they undergo, at one extremity, is inſtantly communicated to the other extremity in the brain, where the ſeat of the ſoul is. And, reciprocally, the ſlighteſt impreſſion made by the ſoul, on the extremities of the nerves, in the *corpus calloſum*, is immediately tranſmitted through the whole extent of every nerve; and it is thus, that the muſcles and members of our bodies are put in motion, and obey the commands of the ſoul.

This wonderful ſtructure of the body, places it in a very cloſe connection with all exterior objects, whether near or remote, which may act upon it, either by immediate contact, as in feeling and taſting; or by their exhalations, as in ſmelling. Bodies, at a

opinion: but their labours may, perhaps, one day inform us, what we are to underſtand by the origin of the nerves, and even, to a certain point, in what manner they tranſmit to the brain the impreſſions which they receive.—*F. E.*

great

great diſtance, act on the ſenſe of hearing, when they make a noiſe, and exert in the air vibrations which ſtrike our ears; they act, likewiſe, upon the ſight, when they are illumined, and tranſmit into our eyes the rays of light, which conſiſt, in like manner, in a certain vibration, cauſed in that medium, much more ſubtile than the air, which we call *Ether*. It is thus that bodies, both near and remote, may act upon the nerves of our body, and produce certain impreſſions in the *corpus calloſum*, from which the ſoul derives it's perceptions.

From every thing, therefore, which makes an impreſſion on our nerves, there reſults a certain change in the brain, of which the ſoul has a perception, and, thereby, acquires the idea of the object which cauſed it. We have here, then, two things to be examined: the one is corporeal, or *material*, which is the impreſſion, or the change produced in the *corpus calloſum* of the brain; the other *ſpiritual*, namely, the perception, or the information, which the ſoul derives from it. It is, if I may ſo expreſs myſelf, from the contemplation of what paſſes in the *corpus calloſum*, that all our knowledge is derived.

You muſt permit me to enter into a more particular detail, on this important article. Let us, firſt, conſider one ſingle ſenſe, ſay, that of ſmelling, which being the leaſt complicated, ſeems the moſt proper to aſſiſt us in our reſearches. Suppoſe all the other ſenſes annihilated, and that a roſe was applied to the noſe; it's exhalations would, at once, excite a certain agitation in the nerves of the noſe, which,

thence

thence tranſmitted to the *corpus calloſum*, will occaſion there, likewiſe, ſome change, and in this conſiſts the *material* circumſtance, which is the ſubject of our inveſtigation. This ſlight change, produced in the *corpus calloſum*, is then perceived by the ſoul, and it thence acquires the idea of the ſmell of a roſe: and this is the *ſpiritual* operation which takes place; but we cannot explain in what manner this is done, as it depends on the incomprehenſible union which the Creator has eſtabliſhed between the body and the ſoul.

It is certain, however, that upon this change, in the *corpus calloſum*, there is excited in the ſoul the idea of the ſmell of a roſe, or the contemplation of this change furniſhes to the ſoul a certain idea, that of the ſmell of a roſe, but nothing more: for, as the other ſenſes are ſuſpended, the ſoul can form no judgment of the nature of the object itſelf, which ſuggeſted this idea; the idea of the ſmell of a roſe alone, was excited in the ſoul. Hence, we comprehend, that the ſoul does not form this idea of itſelf, for it would have remained unknown, but for the preſence of a roſe. But farther, the ſoul is not indifferent with reſpect to it; the perception of this idea is agreeable; the ſoul itſelf is, ſome how, intereſted in it. Accordingly, we ſay, that the ſoul feels the odour of the roſe, and this perception we call *ſenſation*.

It is the ſame with all the other ſenſes; every object, by which they are ſtruck, excites in the *corpus calloſum* a certain change, which the ſoul obſerves with a ſenſation, agreeable or diſagreeable, and from which

which it derives the idea of the object which caufed it. This idea is accompanied with a fenfation, fo much the ftronger, and more intenfe, as the impreffion made on the *corpus callofum* is more lively. It is thus, that the foul, by contemplating the changes produced in the *corpus callofum* of the brain, acquires ideas, and is affected by them; and this is what we underftand by the term *fenfation*.

17th Jan. 1761.

LETTER XCV.

Of the Faculties of the Soul, and of Judgment.

HAD we no other fenfe but that of fmelling, our knowledge would be very limited; we fhould, then, have no other fenfation than that of odours, the diverfity of which, were it ever fo great, could not very much intereft our foul; being reftricted to this, that agreeable fmells would procure fome degree of pleafure, and fuch as are difagreeable, would excite fome difguft.

But this very circumftance carries us forward to a moft important inquiry: Whence is it, that one fmell is agreeable, and another difgufting? It cannot be a matter of doubt, that agreeable fmells excite, in the *callofum*, a different agitation from that which duced by the difagreeable; but how comes it, me agitation, in the *corpus callofum*, can give to the foul, while another is offenfive, and

even,

even, frequently. becomes inſupportable? The cauſe of this difference reſides no longer in body, and matter; we muſt look for it, in the nature of the ſoul itſelf, which enjoys a certain pleaſure in feeling certain agitations, while others excite uneaſineſs: and the real cauſe of this effect we do not know.

Hence we comprehend, that the ſoul does more than ſimply perceive what paſſes in the brain, or *corpus callosum*; it ſubjoins to ſenſation, a judgment reſpecting what it finds agreeable, or diſguſting, and, conſequently, exerciſes, beſide the faculty of perceiving, another, and a different faculty, that of judging: and this judgment is wholly different from the ſimple idea of a ſmell.

The ſame conſideration, of the ſenſe of ſmelling only, diſcovers to us ſtill other acts of the ſoul. When the ſmells are changed, when you apply to the noſe a carnation after a roſe, the ſoul has not only a perception of both ſmells, but, likewiſe, remarks a difference between them. Hence we conclude, that the ſoul ſtill retains the preceding idea, to compare it with that which follows; in this conſiſts *reminiſcence*, or memory, by which we have the power of recalling ideas, antecedent and paſt. Now, the real ſource of memory is entirely concealed from us. We know well, that the body has much to do in it; for experience aſſures us, that diſeaſe, and various accidents, which befall the body, weaken, and frequently deſtroy, the memory: it is equally certain, at the ſame time, that the recollection of ideas is the proper work of the ſoul. A recollected idea is eſſentially

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different from an idea excited by an object. I have a perfect recollection of the ſun, which I ſaw to day, but this idea greatly differs from that which I had while I was looking at the ſun.

Some authors pretend, that when we recall an idea, there happens in the brain an agitation ſimilar to that which firſt produced it; but if this were the caſe, I ſhould actually ſee the ſun; it would no longer be a recollected idea. They admit, indeed, that the agitation which accompanies the recalled idea, is much weaker than that from which the original idea proceeded; but ſtill I am not ſatisfied with this, for it would thence follow, that when I recal the idea of the ſun, it would be much the ſame as when I ſee the moon, the light of which, you will pleaſe to remember, is about 200,000 times weaker than that of the ſun. But actually to look at the moon, and ſimply to recollect the ſun, are two things abſolutely different.

We may ſay with truth, that the recollected ideas are the ſame with the actual ideas; but this identity reſpects only the ſoul; with regard to the body, the actual idea is accompanied with a certain agitation in the brain, whereas the recollected one is deſtitute of it. Accordingly, we ſay, that the idea which I feel, or which an object acting on my ſenſes excites in my ſoul, is a ſenſation; but it can with no propriety be ſaid, that a recollected idea is a ſenſation. To recollect, and to feel, always remain two things, abſolutely different.

When, therefore, the ſoul compares two different ſmells,

ſmells, when it has the idea of the one from the preſence of an object acting on the ſenſe of ſmelling, and that of the other from recollection, it has, in fact, two ideas at once, the actual idea, and the recollected idea: and in pronouncing, whether of the two is more or leſs agreeable, or diſagreeable, it exerts a particular faculty, diſtinct from that by which it only contemplates what is preſented to it.

But the ſoul performs ſtill other operations; when a ſucceſſion of ſeveral different ſmells is preſented to it; for while it is ſtruck with each of theſe, in it's turn, the preceding are recollected, and a notion is thereby acquired of paſt and preſent, and even of future, when new ſenſations are propoſed, ſimilar to thoſe of which it has already had experience. It thence, likewiſe, derives the idea of ſucceſſion, in as much as it undergoes ſeveral impreſſions ſucceſſively, and hence reſults the idea of *duration*, and of *time*. Finally, on remarking the diverſity of ſenſations, which ſucceed each other; it begins to reckon *one*, *two*, *three*, &c. though this ſhould not go farther, from want of ſigns, or names, wherewith to mark numbers. For, ſuppoſing a man has juſt begun to exiſt, and who has hitherto experienced no ſenſations, but thoſe of which I have been ſpeaking; far from having created a language for himſelf, he only knows how to exert his firſt faculties, on the ſimple ideas which the ſenſe of ſmelling preſents to him.

You ſee, then, that the man in queſtion, has already acquired the capacity of forming to himſelf ideas of diverſity, of the preſent, of the paſt, and

even

even of the future; afterwards, of fucceffion, of the duration of time, and of number, or at leaft of the elements of thefe ideas. Some authors pretend, that fuch a man could not acquire the idea of the duration of time, without a fucceffion of different fenfations; but it appears to me, that the fame fenfation, the fmell of the rofe, for example, being continued for a confiderable time together, he would be differently affected by it, than he would, if it were prefently withdrawn. A very long duration, of the fame fenfation, would, at length, become tirefome, which would, neceffarily, excite in him the idea of duration. It muft certainly be allowed, that his foul would be fenfible of a very different effect, if the fenfation were continued long, than if it lafted only for a moment: and the foul will clearly perceive this difference; it will, accordingly, have fome idea of duration, and of time, without any variation of the fenfations.

Thefe reflections which the foul makes, occafioned by it's fenfations, are what properly belong to it's *fpirituality*, the body furnifhing only fimple fenfations. The perception of thefe fenfations is, already, an act of the foul's fpirituality; for a body can never acquire ideas.

20th January, 1761.

LETTER

LETTER XCVI.

Conviction of the Existence of what we perceive by the Senses. Of the Idealists, Egotists, and Materialists.

IN all the sensations which we experience, when one of our senses is struck by any object, it is a matter of high importance to remark, that the soul not only acquires an idea, conformed to the impression made on the nerves, but that it judges, at the same time, there must exist an exterior object, which furnished this idea. Though habit makes us consider this judgment as extremely natural, yet we have reason to be astonished at it, when we examine, more attentively, what then passes in our brain.

An example will place this in a clear light. I shall suppose you looking at the full moon, by night; the rays which enter into your eyes will, at once, paint on the retina, an image similar to the moon, for the minute particles of the retina are, by the rays, put into a vibration similar to that which agitates those of the moon. Now, the retina, being only a contexture of nerves, extremely subtile, you easily comprehend, that these nerves must hence undergo a certain agitation, which will be transmitted to the origin of the nerves in the brain. There will be excited, therefore, likewise, in that portion of the brain, a certain agitation, which is the real object that the soul contemplates, and from which it derives an article of knowledge, which is the idea of the moon.

Consequently, the idea of the moon is nothing else, but the contemplation of this slight agitation, affecting the origin of the nerves.

The activity of the soul is so much attached to the spot in which the nerves terminate, that it absolutely knows nothing of the images painted on the bottom of the eye, and still less of the moon, whose rays have formed these images. The soul, however, does not satisfy itself with the mere speculation of the agitation in the brain, which supplies it immediately with the idea of the moon, it subjoins to this, the judgment, that there really exists, out of us, an object, which we call the moon. This judgment is reduced to the following reasoning.

There has taken place in my brain a certain agitation, a certain impression; I do not absolutely know by what cause it has been produced, as I know nothing even of the images, which are the immediate cause of it upon the retina; nevertheless, I boldly pronounce, that there is a body out of me, the moon, which supplied me with this sensation.

What a consequence? May it not be more probable, that this agitation, or this impression, is produced, in my brain, by some internal cause, such as the motion of the blood, or, perhaps, merely by chance? What right have I, then, to conclude, that the moon actually exists? If I conclude from it, that there is, at the bottom of my eye, a certain image, this might pass; as, in fact, this image is the immediate cause of the impression made on my brain; though it was sufficiently bold to hazard even this

conclusion.

conclusion. But I go much farther, and, because there is a certain agitation in my brain, I proceed to conclude, that there exists, out of my body, nay, in the heavens, a body which is the first cause of such impression, and that this body is the moon.

In sleep, when we imagine we see the moon, the soul acquires the same idea: and, perhaps, a similar agitation is then produced in the brain, as the soul imagines that it then really sees the moon. It is, undoubtedly, certain, that, in this, we deceive ourselves: but what assurance have we, that our judgment is better founded when we are awake? Philosophers have lost their way, more than once, in endeavouring to solve this difficulty.

What I have just said, respecting the moon, takes place with regard to all the bodies which we see. The consequence is not apparent, that there must exist bodies out of us, because our brain undergoes certain agitations, or impressions. This applies even to our own limbs, and to our whole body, of which we know nothing but by means of the senses, and of the impressions which they make in the brain: if, then, these impressions, and the ideas which the soul derives from them, prove nothing as to the existence of body, that of our own body becomes equally doubtful.

You will not, therefore, be surprized, that there should be philosophers, who have openly denied the existence of bodies; and, in truth, it is not easy to refute them. They derive a very strong argument from dreams, in which we imagine, that we see so many bodies, which have no exiſtence. It is ſaid, with truth, that then it is pure illuſion; but what aſſurance have we, that we are not under the power of a ſimilar illuſion when awake? According to theſe philoſophers, it is not an illuſion: the ſoul, they admit, perceives a certain impreſſion, an idea, but they boldly deny it to be a conſequence, that bodies really exiſt, which correſpond to thoſe ideas. The ſupporters of this ſyſtem are called *Idealiſts*, becauſe they admit the *ideas* only of material things, and abſolutely deny their exiſtence. They may, likewiſe, be denominated *Spiritualiſts*, as they maintain, that no beings exiſt, except ſpirits.

And as we do not know other ſpirits, but by means of the ſenſes, or of ideas, there are philoſophers who go ſo far as to deny the exiſtence of all ſpirits, their own ſoul excepted, of the exiſtence of which every one is completely convinced. Theſe are called *Egotiſts*, becauſe they pretend that nothing exiſts but their own ſoul.

To them are oppoſed the philoſophers, whom we denominate *Materialiſts*, who deny the exiſtence of ſpirits, and maintain, that every thing which exiſts is matter, and that what we call our ſoul is only matter, extremely ſubtile, and thereby rendered capable of thought.

24th January, 1761.

LETTER

LETTER XCVII.

Refutation of the Idealifts.

I WISH it were in my power to furnifh you with the arms neceffary to combat the Idealifts and the Egotifts, by demonftrating, that there is a real connection between our fenfations and the objects themfelves, which they reprefent; but the more I think of it, the more I feel my own incapacity.

It would be ridiculous to think of engaging with the Egotifts: for a man who imagines he alone exifts, and who does not believe in my exiftence, would act in contradiction to his own fyftem, if he paid any attention to my reafoning, which, according to him, would be that of an imaginary being. It is, likewife, a hard tafk to confute the Idealifts, nay, it is impoffible to convince, of the exiftence of bodies, a man obftinately determined to deny it. Though no fuch philofophers exifted, it would be highly interefting to be able to convince ourfelves, that as often as our foul experiences fenfations, it may be with certainty concluded, that bodies likewife exift; and that, when my foul is affected by the fenfation of the moon, I may thence boldly infer the exiftence of the moon.

But the union which the Creator has eftablifhed between the foul and the brain, is a myftery fo unfathomable, that all our knowledge of it amounts only to this: Certain impreffions made in the brain, where the feat of the foul is, excite in it certain ideas, or fenfations; but the *how*, of this influence, is abfolutely unknown to us. We ought to fatisfy ourfelves with knowing, that this influence fubfifts, which experience fufficiently confirms; and it is in vain to inveftigate *how* this is produced. Now, the fame experience which proves it, informs us, likewife, that every fenfation always difpofes the foul to believe that there exifts, out of it, fome object which excited fuch fenfation; and that fenfation difcovers to us feveral properties of the object.

It is, then, a moft undoubted fact, that the foul always concludes, from any fenfation whatever, the exiftence of a real object, out of us. This is fo natural to us, from our earlieft infancy, and fo univerfally the cafe with all men, and even with animals, that it cannot, with any propriety, be called a prejudice. The dog that barks when he fees me, is certainly convinced that I exift; for my prefence excites in him the idea of my perfon. The dog, then, is not an idealift. Even the meaneft infects are affured that bodies exift, out of them, and they could not have this conviction, but by the fenfations excited in their fouls.

I believe, therefore, that fenfations include much more than thofe philofophers are difpofed to admit. They are not only fimple perceptions of certain impreffions made in the brain; they fupply the foul not with ideas only, but they effectively reprefent

to

to it objects externally exifting, though we cannot comprehend how this is done.

In fact, what refemblance can there be between the luminous idea of the moon, and the flight impreffion which it's rays may produce in the brain, by means of nerves?

The idea, even in as far as the foul perceives it, has nothing material; it is an act of the foul, which is a fpirit: it is not neceffary, therefore, to look for a real relation between the impreffions of the brain, and the ideas of the foul; it is enough for us to know, that certain impreffions made in the brain, excite certain ideas in the foul, and that thefe ideas are reprefentations of objects externally exifting, of whofe exiftence they give us the affurance.

Thus, when my brain excites in my foul the fenfation of a tree, or of a houfe, I pronounce, without hefitation, that a tree, or a houfe, really exifts, out of me, of which I know the place, the fize, and other properties. Accordingly, we find neither man nor beaft, who calls this truth in queftion. If a clown fhould take it into his head to conceive fuch a doubt; and fhould fay, for example, he does not believe that his bailiff exifts, though he ftands in his prefence, he would be taken for a madman, and with good reafon; but when a philofopher advances fuch fentiments, he expects we fhould admire his knowledge and fagacity, which infinitely furpafs the apprehenfions of the vulgar.

It appears to me, accordingly, abundantly certain, that ſuch extravagant ſentiments would never have been maintained, but from pride, and an affectation of ſingularity: and you will readily agree, that the common people have, in this reſpect, much more good ſenſe than thoſe learned gentlemen, who derive no other advantage from their reſearches, but that of bewildering themſelves in a labyrinth of chimeras, unintelligible to the reſt of mankind.*

Let it be eſtabliſhed, then, as a certain rule, that every ſenſation not only excites in the ſoul an idea, but ſhews it, if I may ſo expreſs myſelf, an external object, of whoſe exiſtence it gives full aſſurance, without practiſing a deception. A very formidable objection, however, is ſtarted againſt this, ariſing from dreams, and the reveries of ſick perſons, in which the ſoul experiences a great variety of ſenſations of objects which no where exiſt. The only reflection I ſhall ſuggeſt on this ſubject is, that it muſt be very natural for us to judge that the objects, the ſenſations of which the ſoul experiences, really exiſt, as we judge after this manner even in ſleep, though then we deceive ourſelves; but it does not thence follow, that we likewiſe deceive ourſelves when we are awake. In order to ſolve this objection, it is

* Mr. *Euler* ſeems here to be confounding two different queſtions, that of the exiſtence of exterior objects, and that of a kind of real reſemblance between theſe objects and the idea which we have of them. *Barclay* has, however, carefully diſtinguiſhed them, and has clearly pointed out the difference. All we can at preſent do, is to refer the reader to the article *Exiſtence*, in the *Encyclopedia*, the only work in which theſe queſtions have been treated with an exact analyſis.—*F. E.*

neceſſary

necessary to know better the difference of the state of the man who is asleep, and of him who wakes; and none, perhaps, know this less than the learned, which must surely be a matter of some surprize to you.

27th January, 1761.

LETTER XCVIII.

The Faculty of Perceiving. Reminiscence, Memory, and Attention. Simple and compound Ideas.

YOU are by this time sensible, that objects, by acting upon our senses, excite in the soul sensations, from which we judge that they really exist, out of us. Though the impressions which occasion these sensations are made in the brain, they present, then, to the soul, a species of image similar to the object which the soul perceives, and which is called the *sensible idea*, because it is excited by the senses. Thus, on seeing a dog, the soul acquires the idea of it, and it is by means of the senses that the soul comes to the knowledge of external objects, and acquires sensible ideas of them, which are the foundation of all our attainments in knowledge.

This faculty of the soul, by which it acquires the knowledge of external things, is denominated the *faculty of perception*, and depends, no doubt, on the wonderful union which the Creator has established between the soul and the brain. Now, the soul has ſtill another faculty, that of recalling ideas already communicated by the ſenſes; and this faculty is named *reminiſcence*, or *imagination*. Thus, having once ſeen an elephant, you will be able to recollect the idea of that animal, though it is no longer before you. There is, however, a mighty difference between actual and recollected ideas: the former make an impreſſion much more lively and intereſting than the latter, but the faculty of recalling ideas is the principal ſource of all our knowledge.

Did we loſe the ideas of objects as ſoon as they ceaſe to act upon our ſenſes, we ſhould never be able to make any reflection, any compariſon; and our knowledge would be entirely confined to the things which we ſhould feel at the moment, all preceding ideas being extinguiſhed, as if we had never poſſeſſed them.

It is, therefore, a faculty eſſential to reaſonable beings, and with which animals too are endowed, that of being able to recollect paſt ideas. You know the faculty of which I ſpeak is *memory*. It by no means follows, however, that we have it always in our power to recall all our paſt ideas. How frequently do we exert ourſelves in vain to recollect certain ideas which we formerly had? Sometimes we forget them entirely; but for the moſt part only partially.

If you ſhould happen, for example, to forget the demonſtration of the Pythagorean theorem; with all your efforts, perhaps, you ſhould not be able to recollect it, but this would be only a partial forgetfulneſs;

fulneſs; for as ſoon as I had again drawn the figure, and put you into the train of the demonſtration, you will preſently recollect it, and this ſecond demonſtration will make on your mind quite a different impreſſion from the firſt. We ſee, then, that the reminiſcence of ideas is not always in our power, though they may not be wholly extinguiſhed; and a ſlight circumſtance is frequently capable of reproducing them.

We muſt, therefore, carefully diſtinguiſh between ſenſible and recollected ideas. Senſible ideas are repreſented to us by the ſenſes; but we ourſelves form recollected ideas, on the model of the ſenſible, as far as we remember them.

The doctrine of ideas is of the laſt importance for the purpoſe of a thorough diſquiſition of the real ſources of human knowledge. And firſt, ideas are diſtinguiſhed into *ſimple* and *complex*. A ſimple idea is that in which the ſoul finds nothing to diſtinguiſh, and remarks no parts different from each other. Such is, for example, the idea of a ſmell, or of a ſpot on a ſubſtance of one colour; ſuch is, likewiſe, that of a ſtar, in which we perceive only one luminous point. A complex idea is a repreſentation in which the ſoul is able to diſtinguiſh ſeveral different things. When, for inſtance, we look attentively at the moon, we diſcover ſeveral dark ſpots, ſurrounded by contours more luminous; we remark, alſo, her round figure, when ſhe is full, and her horned figure, when waxing or waning. On viewing her through the teleſcope,

telescope, there are many other particulars distinguishable.

How many different things do we not perceive in beholding a noble palace, or a fine garden? When you do me the honour to read this letter, you will discover in it the different traits of the characters, which you can with ease distinguish from each other. This, then, is a complex idea, as it contains a variety of simple ideas. Not only this letter, taken in whole, presents a complex idea, from it's consisting of a plurality of words; but every word, too, is a complex idea, being composed of several characters; nay, every character is one, from the singularity of the form which distinguishes it from others: but the elements or points which constitute every character, may be considered as simple ideas, in as much as you no longer perceive in them any diversity. A greater degree of attention will likewise discover some variety in these elements, on viewing them through a microscope.

There is a great difference, therefore, even in the manner of contemplating objects. When we observe them only slightly and transiently, we perceive very little variety; but, to an attentive consideration, every particular detail stands disclosed. A savage, on throwing his eyes over this letter, will take it for a piece of paper scribbled all over, and will distinguish only the black from the white, whereas an attentive reader observes in it the peculiar form of every character. Here, then, we have a new faculty of the

soul,

ſoul, denominated *attention*, by which it acquires the ſimple ideas of the different things that meet in one object.

Attention requires addreſs, the reſult of long and frequent exerciſe, to render it capable of diſtinguiſhing the different parts of an object. A clown and an architect, paſſing by a palace, will both receive the impreſſion of the rays which enter into their eyes; but the architect will diſcover a thouſand minute particulars, of which the clown has no perception. Attention alone produces this difference.

31ſt January, 1761.

LETTER XCIX.

Diviſion of Ideas into clear and obſcure, diſtinct and confuſed. Of Diſtraction.

IF we conſider, in a ſlight manner only, a repreſentation made to us by the ſenſes, the idea which we acquire from it is very imperfect, and we ſay it is *obſcure*: but the more attention that we employ to diſtinguiſh all it's parts, the more *perfect* or *diſtinct* our idea will become. In order to acquire a perfect or diſtinct idea of an object, it is not then ſufficient that it ſhould be repreſented in the brain, by impreſſions made upon the ſenſes, the ſoul, too, muſt apply it's attention, which is properly an act of the ſoul, independent upon the body.

It is farther neceſſary that the repreſentation in the

the brain should be well expressed, and contain the different parts and qualities which characterize the object. This takes place when the object is presented to the senses in a suitable manner. When, for example, I see a piece of writing, at the distance of ten feet, I am unable to read it, let me employ whatever degree of attention I may; the distance of the characters prevents their being accurately expressed on the bottom of the eye, and consequently also in the brain: but if the same writing is brought to a proper distance, I can read it, because then all the characters are distinctly represented on the bottom of the eye.

You know that we employ certain instruments in order to procure a more perfect representation in the organs of sense; such as microscopes and telescopes; which are intended as supplements to the imperfection of vision. But, in employing their assistance, we are incapable of attaining a distinct idea, without attention; otherwise we acquire but an obscure idea, nearly such as we should have had by taking a glimpse of the object only.

I have already remarked, that sensations are by no means indifferent to the soul, but agreeable or disagreeable: and this agreeableness, or it's opposite, excites our attention, unless the soul is pre-occupied by several other sensations which entirely engross it: this last state of the soul is termed *distraction*.

Exercise, likewise, greatly contributes to strengthen attention: and there cannot be a mode of exercise more suitable to children than teaching them to read; for they are thereby laid under the necessity

of

of fixing their attention fucceffively on every character, and of impreffing on their minds a clear idea of the figure of each. It is eafy to fee that this exercife muft be at firft extremely painful; but fuch a habit is fpeedily acquired, that even a child, after a little application, can read with aftonifhing quicknefs. In reading a piece of writing, we muft have a very diftinct idea of every character; thus attention is fufceptible of a very high degree of perfection from exercife.

With what amazing rapidity will a proficient in mufic execute the moft difficult piece, though he never faw it before. It is certain that his attention muft have run over all the notes, one after another, and that he remarked the fignification of each. His attention, however, is not confined only to thefe notes; it prefides, likewife, over the motion of the fingers, not one of which moves but by an exprefs order of the foul; he remarks, likewife, at the fame time, how the other performers execute their parts. It is, upon the whole, altogether furprifing to what a height the addrefs of the human mind may be carried by application and exercife. Shew the fame piece of mufic to a beginner; how much time does it require to imprefs on his mind the fignification of every note, and to give him a complete idea of it: while the mafter acquires it by almoft a fingle glance.

This ability extends equally to all other kinds of objects, in which one man may infinitely furpafs another. There are perfons who, with one glance fixed on a perfon paffing before them, acquire a diftinct idea, not only of all the features of the face,

but

but the particulars of his whole drefs, down to the minuteft trifles, while others are incapable of remarking the moft ftriking circumftances.

We obferve, in this refpect, an infinite difference among men. Some promptly catch all the different marks of an object, and form to themfelves a diftinct idea of it; while that formed by others is extremely obfcure. This difference depends, not only on mental penetration, but likewife on the nature of the objects. A mufician catches at once the whole piece of mufic, and acquires a diftinct idea of it: but prefent him with a piece of writing in Chinefe characters, and he will have only very obfcure ideas indeed of fuch writing: the Chinefe, on the contrary, will know, at firft fight, the real import of each character, but will, in his turn, underftand nothing of mufical notes. The botanift obferves in a plant which he never faw before, a thoufand particulars which efcape the attention of another; and the architect difcerns, by a fingle glance, in a building, many things which another, with a much greater degree of attention, could not have difcovered.

It is always ufeful to form diftinct ideas of the objects prefented to our fenfes; in other words to remark all the parts of which they are compofed, and the marks which diftinguifh and characterize them. From thefe obfervations you will eafily comprehend the divifion of ideas into obfcure and clear, into confufed and diftinct. The more diftinct they are, the more they contribute to the advancement of knowledge.

3d February, 1761.

LETTER C.

Of the Abstraction of Notions. Notions general and individual. Of Genus and Species.

THE senses represent objects only which exist externally; and sensible ideas all refer to them; but of these sensible ideas the soul forms to itself a variety of other ideas, which are indeed derived from these, but which no longer represent objects really existing.

When, for example, I look at the full moon, and fix my attention only on it's contour, I form the idea of roundness; but I cannot affirm, that roundness exists of itself. The moon is round, but the round figure does not exist separately out of the moon. It is the same with respect to all other figures; and when I see a triangular, or square table, I may have the idea of a triangle, or of a square, though such a figure exists no where of itself, or separately from an object possessing that figure.

The ideas of numbers have the same origin. Having seen two or three persons, the soul forms the idea of two or three, without attaching it any longer to the persons. Having already acquired the idea of *three*, the soul is able to proceed, and to form the ideas of greater numbers, of four, five, ten, a hundred, a thousand, and so on, without ever having precisely seen so many things together. A single instance, therefore, in which we have seen two or three objects, may carry the ſoul forward to the formation of the ideas of other numbers, be they ever ſo great.

The ſame thing holds as to figures; and you have the power of forming to yourſelf the idea of a polygon, with 1761 ſides, for example, though you never have ſeen an object of that form, and though no one ſuch, perhaps, ever exiſted.

Here the ſoul exerts a new faculty, which is called the power of *abſtraction;* this takes place when the ſoul fixes it's attention on only one quantity or quality of the object, and conſiders it ſeparately, as if it were no longer attached to the object. When, for inſtance, I put my hand on a heated ſtone, and confine my attention to the heat only, I form from it the idea of heat, which is no longer attached to the ſtone. This idea of heat is formed by abſtraction, as it is ſeparated from the ſtone, and the ſoul might have derived the ſame idea from touching a piece of wood heated, or by plunging the hand into hot water.

Thus, by means of abſtraction, the ſoul forms a thouſand other ideas of the quantities and properties of objects, by ſeparating them afterwards from the objects themſelves: as, when I ſee a red coat, and fix my attention only on the colour, I form the idea of red, ſeparate from the coat, and it is obvious that a red flower, or any other ſubſtance of that colour, would have enabled me to form the ſame idea.

Theſe ideas, acquired by abſtraction, are denominated *notions*, to diſtinguiſh them from ſenſible ideas, which repreſent to us objects really exiſting.

It

It is alleged that the power of abſtraction is a prerogative of men, and of other rational beings, and that the beaſts are entirely deſtitute of it. A beaſt may experience the ſame ſenſation of hot water that we do, but is unable to ſeparate the idea of heat and that of the water itſelf: it knows heat only in ſo far as it is connected with the water, but has not the abſtract idea of heat which we have. It is ſaid, that theſe notions are general ideas, which extend to ſeveral things at once, as we may find heat in ſtone, wood, water, or any other body; but our idea of heat is not attached to any one body; for if my idea of heat were attached to a certain ſtone, which firſt ſupplied me with that idea, I could not affirm that wood or other bodies were hot. Hence it is evident, that theſe notions, or general ideas, are not attached to certain objects, as ſenſible ideas are; and as they diſtinguiſh man from the brute creation, they properly exalt him to a degree of rationality wholly unattainable by the beaſts.

There is ſtill farther a ſpecies of notions, likewiſe, formed by abſtraction, which ſupply the ſoul with the moſt important ſubjects on which to employ it's powers: theſe are the ideas of *genus* and *ſpecies*. When I ſee a pear-tree, a cherry-tree, an apple-tree, an oak, a fir, &c. all theſe ideas are different; I, nevertheleſs, remark in them ſeveral things which they have in common; as the trunk, the branches, and the roots; I ſtop ſhort only at thoſe things which the different ideas have in common, and the object, in which all ſuch qualities meet, I call a *tree*. Thus the idea of tree, which I have formed in this manner, is a *general notion*, and comprehends the ſenſible ideas of the pear-tree, the apple-tree, and, in general, of every tree that exiſts.

Now, *the tree* which correſponds to my idea of tree, no where exiſts; it is not the pear-tree, for then the apple would not be comprehended under it; for the ſame reaſon, it is not the cherry-tree, nor the plumb, nor the oak, &c.; in a word, it exiſts only in my ſoul; it is only an idea, but which is realized in an infinite number of objects. In like manner, when I ſpeak of a *cherry-tree*, it too is a general notion, which comprehends all the cherry-trees that exiſt: this notion is not reſtricted to a particular cherry-tree in my garden: for then every other cherry-tree would be excluded.

With reſpect to general notions, every exiſting object, comprehended under one, is denominated an *individual*, and the general idea, ſay that of the cherry-tree, is denominated *ſpecies* or *genus*. Theſe two words ſignify nearly the ſame thing, but genus is the more comprehenſive, including in it a variety of ſpecies. Thus the notion of a tree may be conſidered as a genus, as it includes the notions of pear-trees, apple-trees, oaks, firs, and ſo on, which are ſpecies; and of ſo many others, each of which contains a great number of exiſting individuals.

This manner of forming general ideas is, therefore, likewiſe, performed by abſtraction, and it is here, chiefly,

chiefly, that the ſoul exerts the activity and performs the operations from which all our knowledge is derived. Without theſe general notions, we ſhould differ nothing from the brutes.

7th February, 1761.

LETTER CI.

Of Language; it's Nature, Advantages, and Neceſſity in order to the Communication of Thought, and the Cultivation of Knowledge.

WHATEVER aptitude a man may have to exerciſe the power of abſtraction, and to furniſh himſelf with general ideas, he can make no conſiderable progreſs without the aid of language, ſpoken or written. Both the one and the other contains a variety of words, which are only certain ſigns, correſponding to our ideas, and whoſe ſignification is ſettled by cuſtom, or the tacit conſent of ſeveral men who live together.

It would appear, from this, that the only purpoſe of language to mankind is mutually to communicate their ſentiments, and that a ſolitary man might do very well without it; but a little reflection only is neceſſary to be convinced, that men ſtand in need of language, as much to purſue and cultivate their own thoughts, as to keep up a communication with others.

To prove this, I remark, firſt, that we have ſcarcely

 a word

a word in any language whofe fignification is attached to one individual object. If each cherry-tree in a whole country had it's proper name, as well as every pear-tree, and, in general, every individual tree; what an enormous complication, in language, would refult from it? Were I under the neceffity of employing a particular term to denote every fheet of paper in my bureau, or if I fhould, from caprice, think fit to give each a particular name, this would be as ufelefs to myfelf as to others.

It is, then, a very imperfect defcription of language to fay, that men have, from the firft, impofed on all individual objects, certain names to ferve them for figns. The words of a language exprefs general notions, and you will rarely find one which marks only a fingle individual. The name, *Alexander the Great*, is applicable to one particular perfon; but then it is a compound name. There may have been many thoufands of Alexanders, and the epithet *great*, extends to an infinite number of things. It is thus, that all men bear names, to diftinguifh them from others, though thefe names may be frequently common to many.

The effence of a language confifts, rather, in it's containing words to denote general notions; as that of tree correfponds to a prodigious number of individual beings. Thefe words ferve not only to convey to others, who underftand the fame language, the fame idea which I affix to the words; but they are, likewife, a great affiftance to me, in reprefenting this idea to myfelf. Without the word tree, which

reprefents

reprefents to me the general notion of a tree, I muft imagine to myfelf at once a cherry-tree, a pear-tree, an apple-tree, a fir, &c. and thence extract what they have in common. This would neceffarily opprefs the mind, and fpeedily involve it in the greateft perplexity. But having, once for all, determined to exprefs, by the term tree, the general notion formed by abftraction, this term always excites in my foul the fame notion, without my having occafion to recollect it's origin; and, accordingly, the word *tree* alone, for the moft part, conftitutes the object of the foul, without the reprefentation of any real tree.

The word *man* is, in like manner, a fign to denote the general notion of what all men have in common, and it would be very difficult to tell or to make the enumeration of all that this notion contains. Would you fay that he is a living two-legged being? A cock would likewife be included in this defcription. Would you fay, in the words of Plato's definition, that he is a two-legged animal without feathers? You have only to ftrip the cock of his feathers, in order to obtain the Platonic man.

I do not know whether thofe who fay that man is an animal endowed with reafon, exprefs themfelves more accurately: for how often do we take for men certain beings of whofe rationality we have no affurance. On viewing an army, I have not the leaft doubt that every foldier is a man, though I have not the fmalleft proof that they are all endowed with reafon. If I were to make an enumeration of all the members neceffary to conftitute a man, fome men would always be found defective in one, perhaps in several of these, or we might find some beast who had them all. On investigating, therefore, the origin of the general notion of man, it is almost impossible to say wherein it consists.

No one, however, has any doubt respecting the signification of the word; because every one, wishing to excite this notion in his soul, has only to think on the word *man*, as if he saw it written on paper, or heard it pronounced, according as the respective language of any one may be.

Hence we see that, for the most part, the objects of our thoughts are not so much the things themselves, as the words by which these things are denoted in language; which greatly facilitates the exercise of thought. What idea, in fact, do we associate with the terms *virtue*, *liberty*, *goodness*, &c.? Not surely a sensible image; but the soul having once formed the abstract notions which correspond to these terms, afterwards substitutes them, in it's thoughts, in place of the things which they denote.

You may easily conceive how many abstractions it was necessary to make, in order to arrive at the notion of *virtue*. The actions of men were first to be considered; they were, then, to be compared with the duties imposed on them; in consequence of this, we give the name of *virtue* to the disposition which a man has to regulate his actions conformably to his duties. But, on hearing the word *virtue* rapidly pronounced in conversation, do we always connect with it this complex notion? And what idea is excited

cited in the mind, on hearing the particle *and* or *alſo* pronounced? It is readily ſeen, that theſe words import a ſpecies of connection, but take what pains you pleaſe to deſcribe this connection, you will find yourſelf under the neceſſity of employing other words, whoſe ſignification it would be equally difficult to explain; and if I were to attempt an explanation of the import of the particle *and*, I muſt make frequent uſe of that very particle.

You are now enabled to judge of what advantage language is to direct our thoughts; and that, without language, we ſhould hardly be in a condition to think at all.

10th February, 1760.

LETTER CII.

Of the Perfections of a Language. Judgments and Nature of Propoſitions, affirmative and negative; univerſal, or particular.

I HAVE been endeavouring to ſhew you, how neceſſary language is to man, not only for the mutual communication of ſentiment and thought, but, likewiſe, for the improvement of the mind, and the extenſion of knowledge.

Theſe ſigns, or words, repreſent, then, general notions, each of which is applicable to an infinite number of objects: as, for inſtance, the idea of hot, and of heat, to every individual object which is hot; and the

the idea, or general notion of *tree*, is applicable to every individual tree in a garden, or a foreſt, whether cherries, pears, oaks, or firs, &c.

Hence you muſt be ſenſible how one language may be more perfect than another. A language always is ſo, in proportion as it is in a condition to expreſs a greater number of general notions, formed by abſtraction. It is with reſpect to theſe notions that we muſt eſtimate the perfection of a language.

Formerly there was no word in the Ruſſian language to expreſs what we call *juſtice*. This was certainly a very great defect; as the idea of juſtice is of very great importance in a great number of our judgments and reaſonings, and as it is ſcarcely poſſible to think of the thing itſelf without a term expreſſive of it. They have, accordingly, ſupplied this defect, by introducing into that language a word which conveys the notion of juſtice.

Theſe general notions, formed by abſtraction, are the ſource of all our judgments and of all our reaſonings. A *judgment* is nothing elſe but the affirmation, or negation, that a notion is applicable, or inapplicable; and when ſuch judgment is expreſſed in words, we call it a *propoſition*. To give an example: *All men are mortal*, is a propoſition which contains two notions; the firſt, that of men in general; and the ſecond, that of mortality, which comprehends whatever is mortal. The judgment conſiſts in pronouncing and affirming, *that the notion of mortality is applicable to all men*. This is a judgment, and, being expreſſed in words, it is a propoſition; and, becauſe

it

it affirms, we call it an *an affirmative propoſition.* If it denied, we would call it *negative*, ſuch as this, *no man is righteous.* Theſe two *propoſitions*, which I have introduced as examples, are *univerſal*, becauſe the one affirms of *all* men, that they are mortal, and the other denies that they are righteous.

There are likewiſe *particular propoſitions*, both negative and affirmative; as, *ſome men are learned*, and *ſome men are not wiſe.* What is here affirmed, and denied, is not applicable to all men, but to *ſome* of them.

Hence we derive four ſpecies of propoſitions. The firſt is that of *affirmative and univerſal propoſitions*, the form of which in general is:

Every A is B.

The ſecond ſpecies contains *negative and univerſal propoſitions*, the form of which in general is:

No A is B.

The third is, that of *affirmative propoſitions*, but *particular*, contained in this form:

Some A is B.

And, finally, the fourth is that of *negative* and *particular propoſitions*, of which the form is:

Some A is not B.

All theſe propoſitions contain, eſſentially, two notions, A and B, which are called the *terms of the propoſition:* the firſt of which affirms or denies ſome thing; and this we call the *ſubject*; and the ſecond, which we ſay is applicable, or inapplicable, to the firſt, is the *attribute.* Thus, in the propoſition, *All men are mortal*, the word *man*, or *men*, is the ſubject, and the word *mortal* the attribute: theſe words are much

much uſed in logic, which teaches the rules of juſt reaſoning.

Theſe four ſpecies of propoſitions may likewiſe be repreſented by figures, ſo as to exhibit their nature to the eye. This muſt be a great aſſiſtance toward comprehending more diſtinctly wherein the accuracy of a chain of reaſoning conſiſts.

As a general notion contains an infinite number of individual objects, we may conſider it as a ſpace in which they are all contained. Thus for the notion of *man* we form a ſpace (*plate* I. *fig.* 1.) in which we conceive all men to be comprehended. For the notion of *mortal*, we form another, (*fig.* 2.) in which we conceive every thing mortal to be comprehended. And when I affirm, *all men are mortal*, it is the ſame thing with affirming, that the firſt figure is contained in the ſecond.

I. Hence it follows, that the repreſentation of an affirmative univerſal propoſition is that in which the ſpace A, (*fig.* 3.) which repreſents the *ſubject* of the propoſition, is wholly contained in the ſpace B, which is the *attribute*.

II. As to negative univerſal propoſitions, the two ſpaces A and B, of which A always denotes the *ſubject*, and B the *attribute*, will be repreſented thus, (*fig.* 4.) the one ſeparated from the other; becauſe we ſay, *no A is B*, or that nothing comprehended in the notion A, is in the notion B.

III. In affirmative particular propoſitions, as, *ſome A is B*, a part of the ſpace A will be comprehended in the ſpace B: (*fig.* 5.) as we ſee here, that ſomething

thing comprehended in the notion A, is likewiſe in B.

IV. For negative particular propoſitions, as, *ſome A is not B*; a part of the ſpace A muſt be out of the ſpace B, (*fig*. 6.) This figure reſembles the preceding; but we here remark, principally, that there is ſomething in the notion A, which is not comprehended in the notion B, or which is out of it.

14th February, 1761.

LETTER CIII.

Of Syllogiſms, and their different Forms, when the firſt Propoſition is univerſal.

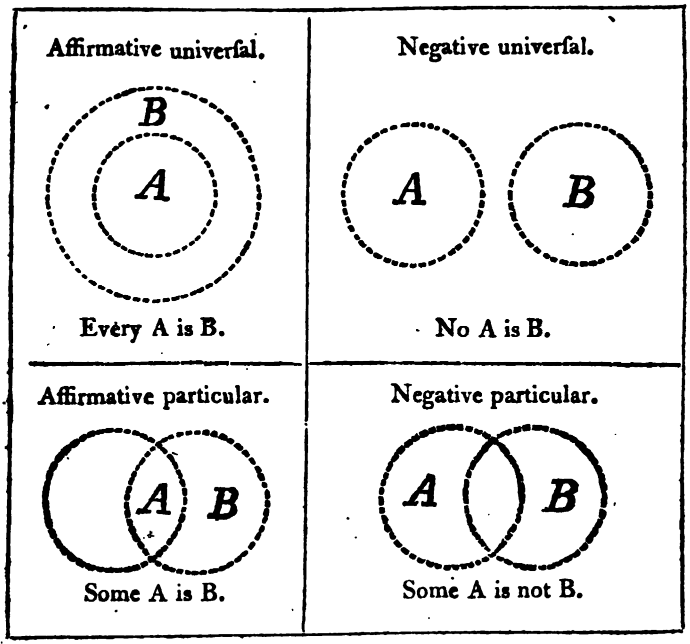
THESE circles, or rather theſe ſpaces, for it is of no importance of what figure they are of, are extremely commodious for facilitating our reflections on this ſubject, and for unfolding all the boaſted myſteries of logic, which that art finds it ſo difficult to explain; whereas, by means of theſe ſigns, the whole is rendered ſenſible to the eye. We may employ, then, ſpaces formed at pleaſure to repreſent every general notion, and mark the ſubject of a propoſition, by a ſpace containing A, and the attribute, by another which contains B. The nature of the propoſition itſelf always imports either that the ſpace of A is wholly contained in the ſpace B, or that it is partly contained in that ſpace; or that a part, at leaſt,

leaſt, is out of the ſpace B; or, finally, that the ſpace A is wholly out of B.*

The two laſt caſes, which repreſent particular propoſitions, ſeem to contain a doubt, as it is not decided, whether it be a great part of A which is contained, or not contained, in B. It is even poſſible,

* Mr. Euler, who is ever minutely exact in all his details, ſubjoins here the following diagram, with this ſhort introduction: "I ſhall once more give you a viſible repreſentation of theſe figures "or emblems of the four ſpecies of propoſitions."

Emblems of the four Species of Propoſitions.



The omiſſion of this ſcheme, in the Paris edition, is the more unaccountable, that the very next paragraph immediately refers to it, and is lame and inconcluſive without it.—*E. E.*

in

in the cafe of a particular propofition, that the notion A may contain the notion B entirely, as in *plate* I. *fig.* 7; and that, at the fame time, as is clear from the figure, a part of the fpace A may be in the fpace B, and that a part of A may no tbe in B. Now, if A were, for example, the idea of *tree* in general, and B that of *oak*, which is contained wholly in the firft, the following propofitions might be formed:

I. All oaks are trees.

II. Some trees are oaks.

III. Some trees are not oaks.

In like manner, if of two fpaces one is entirely out of the other, as in *plate* I. *fig.* 4. I can as well fay, *no A is B*, as *no B is A;* as if I were to fay: no man is a tree, and no tree is a man.

In the third cafe, where the two notions have a part in common, as in *plate* I. *fig.* 5. it may be faid:

I. Some A is B.

II. Some B is A.

III. Some A is not B.

IV. Some B is not A.

This may fuffice to fhew you how all propofitions may be reprefented by figures: but their greateft utility is manifeft in reafonings which, when expreffed in words, are called *fyllogifms*, and of which the object is to draw a juft conclufion from certain given propofitions. This method will difcover to us the true forms of all fyllogifms.

Let us begin by an affirmative univerfal propofition: Every A is B, (*plate* I. *fig.* 3.) where the fpace A is wholly in the fpace B, and let us fee how a third

notion

notion C, muſt be referred to each of the other two notions A and B, in order to draw a fair concluſion. It is evident in the following caſes.

I. If the notion C is entirely contained in the notion A, it will be ſo, likewiſe, in the notion B: (*plate* I. *fig.* 8.) hence reſults this form of ſyllogiſm:

Every A is B:
But Every C is A:
Therefore Every C is B.

Which is the concluſion.

Let the notion A, for example, comprehend all trees; the notion B every thing that has roots, and the notion C all oaks, and then our ſyllogiſm will run thus:

Every tree has roots:
But Every oak is a tree:
Therefore Every oak has roots.

II. If the notion C has a part contained in A, that part will likewiſe be ſo in B, becauſe the notion A is wholly included in the notion B, (*plate* I. *fig.* 9 and 10.)

Hence reſults the ſecond form of ſyllogiſm:

Every A is B:
But Some C is A:
Therefore Some C is B.

he notion C were entirely out of the notion A, g would follow with reſpect to the notion B: t happen that notion C ſhould be entirely out (*fig.* 11.) or wholly in B, (*fig.* 12.) or partly B, (*fig.* 13.) ſo that no concluſion could be l.

III. But

III. But if notion C were wholly out of notion B, it would likewise be wholly out of notion A, as we see in *fig.* 11. Hence results this form of syllogism:

Every A is B:

But No C is B, or no B is C:

Therefore No C is A.

IV. If the notion C has a part out of the uotion B, that same part will certainly likewise be out of the notion A, because this last is wholly in the notion B, (*fig.* 14.) Hence this form of syllogism:

Every A is B:

But Some C is not B:

Therefore Some C is not A.

V. If the notion C contains the whole of notion B, part of notion C will certainly fall into notion A: (*fig.* 15.) Hence this form of syllogism.

Every A is B:

But Every B is C:

Therefore Some C is A.

No other form is possible, while the first proposition is affirmative and universal.

Let us now suppose the first proposition to be negative and universal; namely,

No A is B.

It is represented in *fig.* 4. where the notion A is entirely out of notion B; and the following cases will furnish conclusions.

I. If notion C is entirely in notion B, it must likewise be entirely out of notion A, (*fig.* 16.) Hence this form of syllogism:

No A is B:
But Every C is B:
Therefore No C is A.

II. If notion C is entirely comprehended in notion A, it muſt alſo be entirely excluded from notion B, (*fig.* 17.) Hence a ſyllogiſm of this form:

No A is B:
But Every C is A:
Therefore No C is B.

III. If notion C has a part contained in notion A, that part muſt certainly be out of notion B; as in *fig.* 18. or in *fig.* 19. and 20. Hence a ſyllogiſm of this form:

No A is B:
But Some C is A, or ſome A is C:
Therefore Some C is not B.

IV. In like manner, if notion C has a part contained in B, that part will certainly be out of A: as in *fig.* 21. as alſo *fig.* 22. and 23. Hence the following ſyllogiſm:

No A is B:
But Some C is B, or ſome B is C:
Therefore Some C is not A.

As to the other forms, in which the firſt propoſition is particular, affirmative, or negative; I ſhall ſhew, in another letter, how they may be repreſented by figures.

17th February, 1761.

LETTER

LETTER CIV.

Different Forms of Syllogiſms, whoſe firſt Propoſition is particular.

IN the preceding letter I have preſented you with the different forms of ſyllogiſms, or ſimple reaſonings, which derive their origin from the firſt propoſition, when it is univerſal, affirmative, or negative. It ſtill remains that I lay before you thoſe ſyllogiſms, whoſe firſt propoſition is particular, affirmative, or negative, in order to have all poſſible forms of ſyllogiſm that lead to a fair concluſion.

Let, then, the firſt propoſition, affirmative, and particular, be expreſſed in this general form.

Some A is B. (*Plate* I. *fig.* 5.)

in which a part of the notion A is contained in the notion B.

Let us introduce a third notion C, which, being referred to notion A, will either be contained in notion A, as in *fig.* 24, 25, and 26; or will have a part in the notion A, as in *fig.* 27, 28, and 29; or will be entirely out of notion A, as in *fig.* 1, 2, and 3, of *plate* II. No concluſion can be drawn in any of theſe caſes; as it might be poſſible for notion C to be entirely within notion B, or in part, or not at all.

But if notion C contains, in itſelf, notion A, it is certain, that it will likewiſe contain a part of notion B: as in *fig.* 4 and 5, of *plate* II. Hence reſults this form of ſyllogiſm:

Some A is B: But Every A is C:
Therefore Some C is B.

It is the fame when we compare notion C with notion B: we can draw no conclufion unlefs notion C contains notion B entirely; (fee *fig.* 6 and 7.) for in that cafe, as notion A has a part contained in notion B, the fame part will then certainly be contained, likewife, in C: hence we obtain this form of fyllogifm:

Some A is B:
But Every B is C:
Therefore Some C is A.

Let us finally fuppofe, that the firft propofition is negative and particular, namely,

Some A is not B.

It is reprefented in *plate* II. *fig.* 8. in which part of notion A is out of notion B.

In this cafe, if the third notion C contains notion A entirely, it will certainly alfo have a part out of notion B, as in *fig.* 9 and 10: which gives this fyllogifm:

Some A is not B:
But Every A is C:
Therefore Some C is not B.

Again, if notion C is wholly included in notion B, as A has a part out of B, that fame part will likewife certainly be out of C, (fee *fig.* 11 and 12.) Hence this form of fyllogifm:

Some A is not B:
But Every C is B:
Therefore Some A is not C.

It may be of ufe to collect all thefe forms of fyllogifm into one table, in order to confider them at a fingle glance.

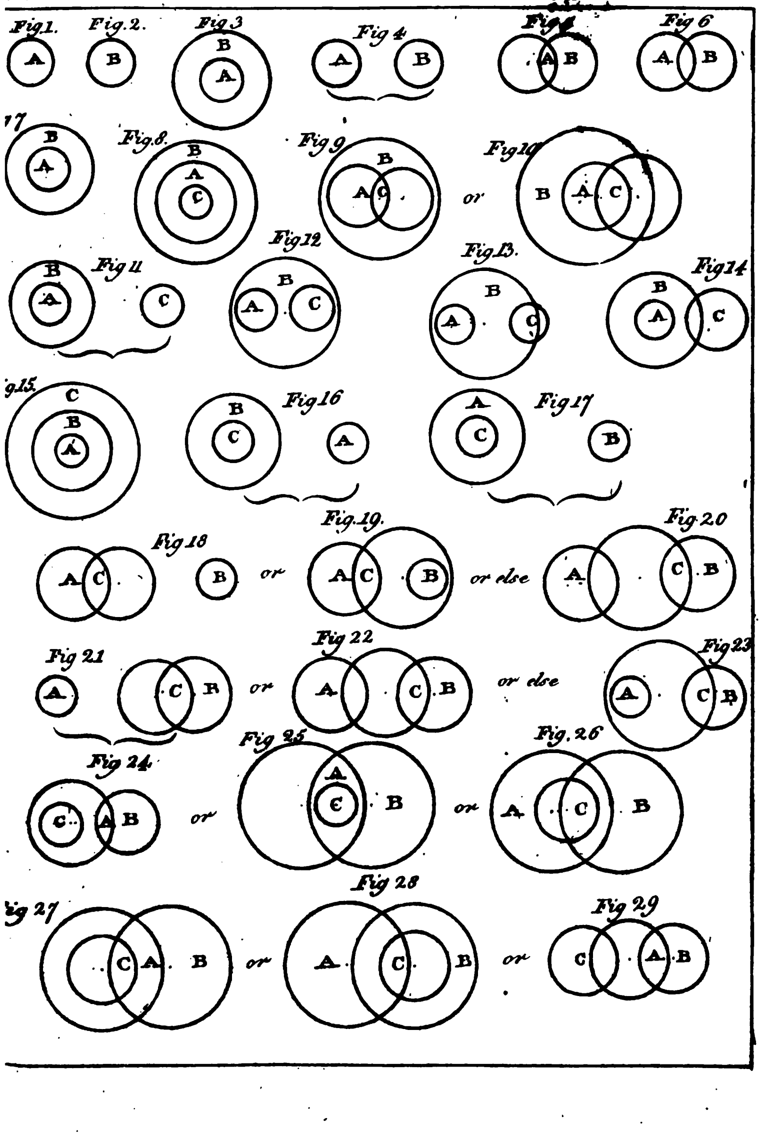


Fig 1.
Fig. 2.
Fig 3
Fig 4
Fig 6
Fig. 8.
Fig 9
Fig 10
Fig 11
Fig 12
Fig 13.
Fig 14
Fig 16
Fig 17
Fig 18
Fig. 19.
Fig 20
Fig 21
Fig 22
Fig 23
Fig 24
Fig 25
Fig. 26
Fig 28
Fig 29
or
or else

I. Every A is B: But Every C is A: Therefore Every C is B.	XI. No A is B: But Some C is B: Therefore Some C is not A.
II. Every A is B: But Some C is A: Therefore Some C is B.	XII. No A is B: But Some B is C: Therefore Some C is not A.
III. Every A is B: But No C is B: Therefore No C is A.	XIII. Some A is B: But Every A is C: Therefore Some C is B.
IV. Every A is B: But No B is C: Therefore No C is A.	XIV. Some A is B: But Every B is C: Therefore Some C is A.
V. Every A is B: But Some C is not B: Therefore Some C is not A.	XV. Some A is not B: But Every A is C: Therefore Some C is not B.
VI. Every A is B: But Every B is C: Therefore Some C is A.	XVI. Some A is not B: But Every C is B: Therefore Some A is not C.
VII. No A is B: But Every C is A: Therefore No C is B.	XVII. Every A is B: But Some A is C: Therefore Some C is B.
VIII. No A is B: But Every C is B: Therefore No C is A.	XVIII. No A is B: But Every A is C: Therefore Some C is not B.
IX. No A is B: But Some C is A: Therefore Some C is not B.	XIX. No A is B: But Every B is C: Therefore Some C is not A.
X. No A is B: But Some A is C: Therefore Some C is not B.	XX. Every A is B: But Every A is C: Therefore Some C is B.

Of theſe twenty forms, I remark, that XVI. is the ſame with V. the latter changing into the former, if you write C for A, and A for C, and begin with the ſecond propoſition: there are, accordingly, but nineteen different forms.

The foundation of all theſe forms is reduced to two principles, reſpecting the nature of *containing* and *contained.*

I. *Whatever is in the thing contained, muſt likewiſe be in the thing containing.*

II. *Whatever is out of the containing, muſt likewiſe be out of the contained.*

Thus, in the laſt form, where the notion A is contained entirely in notion B, it is evident, that if A is contained in the notion C, or makes a part of it, that ſame part of notion C will certainly be contained in notion B, ſo that ſome C is B.

Every ſyllogiſm, then, conſiſts of three propoſitions, the two firſt of which are called the *premiſes*, and the third the *concluſion*. Now, the advantage of all theſe forms, to direct our reaſonings, is this, that if the premiſes are both true, the concluſion, infallibly, is ſo.

This is, likewiſe, the only method of diſcovering unknown truths. Every truth muſt always be the concluſion of a ſyllogiſm, whoſe premiſes are indubitably true. Permit me only to add, that the former of the premiſes is called the *major* propoſition, and the other the *minor*.

21ſt February, 1761.

LETTER

LETTER CV.

Analyſis of ſome Syllogiſms.

IF you have paid attention to all the forms of ſyllogiſm, which I have propoſed, you muſt ſee, that every ſyllogiſm neceſſarily conſiſts of three propoſitions: the two firſt are called premiſes, and the third, the concluſion. Now the force of the nineteen forms, laid down, conſiſts in this property common to them all, that if the two firſt propoſitions, or the premiſes, are true, you may reſt, confidently aſſured of the truth of the concluſion.

Let us conſider, for example, the following ſyllogiſm.

NO VIRTUOUS MAN IS A SLANDERER;
But SOME SLANDERERS ARE LEARNED MEN:
Therefore SOME LEARNED MEN ARE NOT VIRTUOUS.

Whenever you allow me the two firſt propoſitions, you are obliged to allow the third, which neceſſarily follows from it.

This ſyllogiſm belongs to form XII. The ſame thing holds with regard to all the others, which I have laid down, and which the figures, whereby I have repreſented them, render ſenſible. Here we are preſented with three notions: *(plate* II. *fig.* 13.) that of virtuous men, that of ſlanderers, and that of learned men.

Let the ſpace A repreſent the firſt, ſpace B the ſecond, and ſpace C the third. It being ſaid, in the firſt propoſition, That no virtuous man is a ſlanderer; we maintain, that nothing contained in the notion of the virtuous man, that is, in the ſpace A, is comprehended in the notion of the ſlanderer: that is, ſpace B: therefore ſpace A is wholly out of ſpace B, (ſee *plate* II. *fig.* 14.)

But it is ſaid, in the ſecond propoſition, that ſome men comprehended in notion B, are, likewiſe, contained in that of learned, that is, in ſpace C: or elſe, you may ſay, that part of ſpace B is within ſpace C; (*plate* II. *fig.* 15.) where the part of ſpace B, included in C, is marked with a *; which will be, likewiſe, part of ſpace C. Since, therefore, ſome part of ſpace C is in B, and that the whole ſpace B is out of ſpace A, it is evident, that the ſame part of ſpace C muſt, likewiſe, be out of ſpace A, that is, *ſome learned men are not virtuous.*

It muſt be carefully remarked, that this concluſion reſpects only the part * of notion C, which is comprehended in notion B: for as to the reſt, it is uncertain, whether it be likewiſe excluded from notion A, as in *plate* II. *fig.* 16, or wholly contained in it, as in *plate* II. *fig.* 17, or only in part, as in *plate* II. *fig.* 18.

Now, this being left uncertain, the remainder of ſpace C falls not at all under conſideration; the concluſion is limited to that only which is certain, that is to ſay, the ſame part of ſpace C, contained in ſpace B, is certainly out of ſpace A, for this laſt is wholly out of ſpace B.

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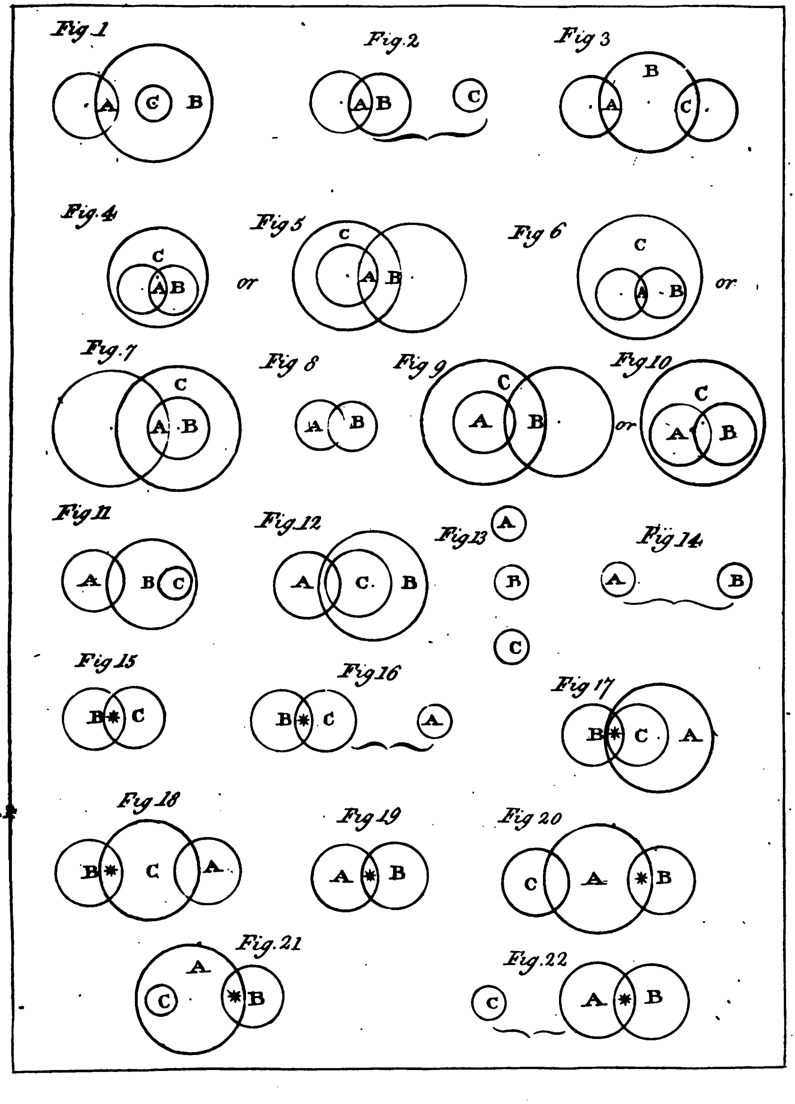
Fig. 1
A
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Fig. 2
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Fig. 3
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Fig. 4
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or
Fig. 5
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Fig. 6
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or
Fig. 7
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Fig. 8
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Fig. 9
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or
Fig. 10
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Fig. 21
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Fig. 22
C
A
B

The juſtneſs of all the other forms of ſyllogiſm may be demonſtrated in like manner; but all thoſe which deviate from the nineteen forms laid down, or which are not comprehended under them, are deſtitute of foundation, and lead to error and falſhood.

You will clearly diſcern the fault of ſuch a ſyllogiſm, by an example, not reducible to any of the nineteen forms:

SOME LEARNED MEN ARE MISERS:

But NO MISER IS VIRTUOUS:

Therefore SOME VIRTUOUS MEN ARE NOT LEARNED.

This third propoſition, may, perhaps, be true; but it does not follow from the premiſes. They too (the premiſes) may very well be true, and, in the preſent inſtance, they actually are ſo, but the third is not, for that, a fair concluſion: becauſe it is contrary to the nature of juſt ſyllogiſm, in which the concluſion always muſt be true, when the premiſes are ſo. Accordingly, the fault of the form, above propoſed, is immediately diſcovered, by caſting your eyes on *fig.* 13. of *plate* II. Let ſpace A contain all the learned; ſpace B all the avaricious; and ſpace C all the virtuous. Now, the firſt propoſition is repreſented by *fig.* 19. in which part * of ſpace A, (the learned) is contained in ſpace B, (the avaricious).

Again, in the ſecond propoſition, the whole ſpace C, (the virtuous) is out of ſpace B, (the avaricious): but it by no means follows, (*fig.* 20.) that part of ſpace C muſt be out of ſpace A.

It is even poſſible for ſpace C, to be entirely within

ſpace

II. You muſt carefully diſtinguiſh theſe three terms of every ſyllogiſm. Two of them, namely, B and C, enter into the concluſion, the one of which, C, is the *ſubject*, and the other, B, the *attribute*, or *predicate*. In logick, the ſubject of the concluſion, C, is called the *minor term*, and the *predicate* of the concluſion, B, the *major term*. But the third notion, or the term A, is found in both premiſes, and it is combined with both the other terms, in the concluſion. This term, A, is called the *mean* or *medium term*. Thus, in the following example.

NO MISER IS VIRTUOUS:

But SOME LEARNED MEN ARE MISERS:

Therefore SOME LEARNED MEN ARE NOT VIRTUOUS.

The notion *learned* is the minor term, that of *virtuous* is the major, and the notion of *miſer*, is the mean term.

III. As to the order of the propoſitions, it is a matter of indifference, whether of the premiſes is in the firſt or ſecond place, provided the concluſion holds the laſt, it being the conſequence from the premiſes. Logicians have, however, thought proper to lay down this rule:

The firſt propoſition is always that which contains the predicate of the concluſion, or the major term; for this is the reaſon that we give to this propoſition the name of the major propoſition.

The ſecond propoſition contains the minor term, or the ſubject of the concluſion, and hence it has the name of the minor propoſition.

Thus, the *major propoſition* of a ſyllogiſm contains the

the mean term, with the major term, or predicate of the conclufion; and the *minor propofition* contains the mean term, with the minor term, or fubject, of the conclufion.

IV. Syllogifms are diftinguifhed under different *figures*, according as the mean term occupies the place of *fubject*, or *attribute*, in the premifes.

Logicians have eftablifhed four figures of fyllogifms, which are thus defined:

The *firft figure* is that in which the mean term is the fubject, in the major propofition, and the predicate, in the minor.

The *fecond figure*, that in which the mean term is the predicate, in both the major propofition, and the minor.

The *third figure*, that in which the mean term is the fubject, in both the major and minor propofitions. Finally,

The *fourth figure*, is that in which the mean term is the predicate, in the major propofition, and the fubject, in the minor.

Let P be the minor term, or fubject of the conclufion: Q the major term, or predicate, of the conclufion, and M the mean term; the four figures of fyllogifm will be reprefented in the manner following:

Figure Firft.

Major Propofition	M	—	—	Q
Minor Propofition	P	—	—	M
Conclufion	P	—	—	Q

Figure

Figure Second.

Major Propofition	Q	— —	M
Minor Propofition	P	— —	M
Conclufion	P	— —	Q

Figure Third.

Major Propofition	M	— —	Q
Minor Propofition	M	— —	P
Conclufion	P	— —	Q

Figure Fourth.

Major Propofition	Q	— —	M
Minor Propofition	M	— —	P
Conclufion	P	— —	Q

V. Again, according as the propofitions themfelves are univerfal, or particular, affirmative, or negative, each figure contains feveral forms, called *Modes*. In order, the more clearly, to reprefent thefe modes of each figure, we mark by the letter A, univerfal affirmative propofitions; by the letter E, univerfal negative propofitions; by the letter I, particular affirmative propofitions: and, finally, by the letter O, particular negative propofitions: or elfe,

A reprefents an univerfal affirmative propofition.
E reprefents an univerfal negative propofition.
I reprefents a particular affirmative propofition.
O reprefents a particular negative propofition.

VI. Hence, our nineteen forms of fyllogifm, above defcribed, are reducible to the four figures, which I have juft laid down, as in the following tables;

I. Modes

I. Modes of the Firſt Figure.

1ſt Mode. A. A. A. Every M is Q; But Every P is M: Therefore Every P is Q.	2d Mode. A. I. I. Every M is Q; But Some P is M: Therefore Some P is Q.
3d Mode. E. A. E. No M is Q; But Every P is M: Therefore no P is Q.	4th Mode. E. I. O. No M is Q; But Some P is M: Therefore Some P is not Q.

II. Modes of the Second Figure.

1ſt Mode. A. E. E. Every Q is M; But No P is M: Therefore No P is Q.	2d Mode. A. O. O. Every Q is M; But Some P is not M: Therefore Some P is not Q.
3 Mode. E. A. E. No Q is M; But Every P is M: Therefore No P is Q.	4th Mode. E. I. O. No Q is M; But Some P is M: Therefore Some P is not Q.

III. Modes

III. Modes of the Third Figure.

1st Mode. A. A. I. Every M is Q; But Every M is P: Therefore Some P is Q.	2d Mode. I. A. I. Some M is Q; But Every M is P: Therefore Some P is Q.
3d Mode. A. I. I. Every M is Q; But Some M is P: Therefore Some P is Q.	4th Mode. E. A. O. No M is Q; But Every M is P: Therefore Some P is not Q.
5th Mode. E. I. O. No M is Q; But Some M is P: Therefore Some P is not Q.	6th Mode. O. A. O. Some M is not Q; But Every M is P: Therefore Some P is not Q.

IV. Modes of the Fourth Figure.

1st Mode. A. A. I. Every Q is M; But Every M is P: Therefore Some P is Q.	2d Mode. I. A. I. Some Q is M; But every M is P: Therefore Some P is Q.
3d Mode. A. E. E. Every Q is M; But No M is P: Therefore No P is Q.	4th Mode. E. A. O. No Q is M; But Every M is P: Therefore Some P is not Q.

5th Mode.
E. I. O.
No Q is M:
But Some M is P:
Therefore Some P is not Q.

You

You ſee, then, that the firſt figure has four modes; the ſecond four; the third ſix; the fourth five; ſo that the whole of theſe modes, together, is *nineteen*, being preciſely the ſame forms which I have above explained, and have juſt now diſpoſed in the four figures. In other reſpects, the juſtneſs of each of theſe modes has been already demonſtrated, by the ſpaces which I employed, to mark the notions. The only difference conſiſts in this, that here I make uſe of the letters, P, Q, M, inſtead of A, B, C.

28th February, 1761.

LETTER CVII.

Obſervations and Reflections, on the different Modes of Syllogiſm.

I FLATTER myſelf, that the following reflections will contribute, not a little, to place the nature of ſyllogiſms in a clearer light. You muſt pay particular attention to the ſpecies of the propoſitions which compoſe the ſyllogiſms, of each of our four figures, that is to ſay, whether they are,

1. Univerſal affirmative, the ſign of which is A; or
2. Univerſal negative, the ſign of which is E; or
3. Particular affirmative, the ſign of which is I; or, finally,
4. Particular negative, the ſign of which is O; and you will readily admit the juſtneſs of the following reflections:

I. In no one inſtance are both premiſes negative propoſitions. Logicians have hence formed this rule:

From two negative propoſitions, no concluſion can be drawn.

The reaſon is evident, for laying down P and Q, as the terms of the concluſion, and M as the mean term, if both premiſes are negative, the affirmation is, that the notions P and Q, are either wholly, or in part, out of M: it is, accordingly, impoſſible to conclude any thing, reſpecting the conformity, or diſconformity, of the notions P and Q. Though I knew from hiſtory, that the Gauls were not Romans, and that neither were the Celtæ Romans, this would not contribute in the leaſt to inform me whether the Celtæ were Gauls or not. Two negative premiſes, therefore, lead to no concluſion.

II. Both premiſes are, in no one inſtance, particular propoſitions; hence this rule is logic:

From two particular propoſitions, no concluſion can be drawn.

Thus, for example, becauſe ſome learned men are poor, and ſome others malevolent, it is impoſſible to conclude, that thoſe who are poor are malevolent, or that they are not ſo. If you reflect ever ſo little on the nature of a conſequence, you muſt immediately perceive, that two particular premiſes lead to no concluſion whatever.

III. *If either of the premiſes is negative, the concluſion too muſt be negative.*

This is the third rule which logic preſcribes. When ſomething

ſomething is denied in the premiſes, it is impoſſible to affirm any thing in the concluſion; we muſt abſolutely deny there likewiſe. This rule is perfectly confirmed by all the laws of ſyllogiſm, whoſe juſtice has been above demonſtrated.

IV. *If one of the premiſes is particular, the concluſion too muſt be particular.*

This is the fourth rule preſcribed in logic. The character of particular propoſitions being the word *ſome*, if we ſpeak only of ſome in one of the premiſes, it is impoſſible to ſpeak generally, in the concluſion; it muſt be reſtricted to ſome. This rule, likewiſe, is confirmed by all the laws of ſyllogiſm, whoſe juſtneſs is indubitable.

V. *When both premiſes are affirmative, the concluſion is ſo likewiſe. But though both premiſes may be univerſal, the concluſion is not always univerſal, ſometimes it is particular only*, as in the *firſt* mode of figures third and fourth.

VI. Beſide univerſal and particular propoſitions, we, ſometimes, make uſe of *ſingular* propoſitions, the ſubject of which is an individual; as when I ſay:

Virgil was a great Poet.

The name of *Virgil* is not a general notion, containing ſeveral beings in itſelf: it is the proper name of a real individual, who lived a great many years ago. This propoſition is called *ſingular*; and when it is introduced into a ſyllogiſm, it is of importance to determine, whether we are to conſider it as holding the rank of an univerſal, or particular, propoſition.

 VII. Certain

VII. Certain authors infift, that a fingı fition muft be ranked in the clafs of part being confidered, that a particular propofi only of fome beings comprehended in t whereas an univerfal propofition fpeaks of fay thefe authors, when we fpeak of only being, this is ftill lefs than when we fpeak and, confequently, a fingular propofitio confidered as very particular.

VIII. However well founded this reafı appear, it cannot be admitted. The effenı ticular propofition confifts in this, that i fpeak of all the beings, comprehended in of the fubject, whereas an univerfal propofi of all, without exception. Thus, when it

Some citizens of Berlin are rich,

the fubject of this propofition is the notio *citizens* of Berlin; but this fubject is not ı it's extent, it's fignification is exprefsly r *fome*: and, by this, particular propofitiı fentially diftinguifhed from univerfal, as only on a part of the beings comprehenc fubject.

IX. It is clearly evident, from this ren *fingular propofition muft be confidered as un* in fpeaking of an individual, fay Virgil, i fpect, reftricts the notion of the fubjec Virgil himfelf, but rather admits it in all *and, for this reafon, the fame rules which univerfal propofitions apply, likewife, to fin* *ſitions.* The following is, accordingly, a very good ſyllogiſm :

VOLTAIRE IS A PHILOSOPHER ;

But VOLTAIRE IS A POET :

Therefore SOME POETS ARE PHILOSOPHERS.

And it would be faulty, if the two premiſes were particular propoſitions, but being conſidered as univerſal, this ſyllogiſm belongs to figure third, and the firſt mode of the form A. A. I. The individual idea of Voltaire is the mean term, which is the ſubject of both major and minor ; and this is the character of figure third.

X. Finally, I muſt remark, that hitherto I have ſpoken only of *ſimple propoſitions*, which contain only two notions, the one of which is affirmed or denied, univerſally, or particularly. With reſpect to *compound propoſitions*, logic preſcribes peculiar rules.

3d March, 1761.

LETTER CVIII.

Hypothetical Propoſitions, and Syllogiſms conſtructed of them.

WE have, hitherto, conſidered ſimple propoſitions only, or ſuch as contain but two notions, the one of which is the ſubject, the other the predicate. Theſe propoſitions can form no other ſyllogiſms, except thoſe which I have laid before you, and which are contained in the four figures above explained. But we, likewiſe, frequently employ

 compound

It is, undoubtedly, true, that the Gazette may not ſpeak truth; nevertheleſs, it is very poſſible that peace may be approaching.

The other form is equally erroneous;

If THE GAZETTE IS TRUE, PEACE APPROACHES;
But PEACE APPROACHES:
Therefore THE GAZETTE IS TRUE.

Let us ſuppoſe, that this conſolatory truth, *peace approaches*, were revealed to us, ſo as to be put beyond the poſſibility of doubt, it would by no means follow that Gazettes are true, or that they never contain untruths. I hope, at leaſt, that peace is at hand, though I am very far from putting confidence in the truth of Gazettes.

Theſe two laſt forms of ſyllogiſms, therefore, are fallacious; but the two preceding are certainly good, and never lead into error, provided that the firſt conditional propoſition is true, or that the laſt part be a neceſſary conſequence of the firſt.

Of this conditional propoſition:

If A is B, C will be D.

The firſt part, *A is B*, is called the *antecedent*, and the other, *C will be D*, the *conſequent*. Logic preſcribes the two following rules to direct us in this ſtyle of reaſoning:

I. *Whoever admits the antecedent, muſt likewiſe admit the conſequent.*

II. *Whoever denies, or rejects, the conſequent, muſt likewiſe deny, or reject, the antecedent.*

But you may very well deny the antecedent without

out denying the consequent, and likewise admit the consequent without admitting the antecedent.

There are still other compound propositions, of which also syllogisms may be formed. It will, perhaps, be sufficient to produce a single example. Having this proposition:

Every substance is body or spirit:

the conclusion will run in the following manner:

I. But Such a substance is not body;
Therefore It is spirit.

II. But Such a substance is body;
Therefore It is not spirit.

But it is entirely unnecessary to detain you longer on this subject.

7th March, 1761.

LETTER CIX.

Of the Impression of Sensations on the Soul.

HAVING endeavoured to unfold the principles of logic, whose object it is to lay down infallible rules for right reasoning, I must still detain you a little longer on the subject of ideas.

We, undoubtedly, derive them, in the first instance, from real objects, which strike our senses; and as far as they are struck with any object, a sensation corresponding is thereby excited in the soul. Not only do the senses represent to the soul the idea of that object, but they give it full assurance of it's existence impreſſion, or receiving it afreſh? And, though it be very certain, that the action of objects, on the ſenſes, produces ſome change in the brain; this change is very different from the idea which is occaſioned by it; and the ſentiment of pleaſure, or diſguſt, as well as the judgment reſpecting the object itſelf, which cauſed this impreſſion, equally require a being wholly different from matter, and endowed with qualities of quite a different nature.

Our advances in knowledge are not limited to ideas perceived: the ſame ideas, recollected in the memory, form for us, by abſtraction, general ideas of them, which contain, at once, a great number of individual ideas; and how many abſtract ideas do we form, reſpecting the qualities and accidents of objects, which have no relation to any thing corporeal, ſuch as the notions of virtue, of wiſdom, &c.?

This, after all, refers only to the *underſtanding*, which comprehends but a part of the faculties of the ſoul; the other part is not leſs extenſive, namely, *the will* and *liberty*, on which depend all our reſolutions and actions. There is nothing in the body relative to this quality, by which the ſoul freely determines itſelf to certain actions, even after mature deliberation. It pays regard to motives, without being forced to ſubmit to their influence; and liberty is ſo eſſential to it, as well as to all ſpirits, that it would be as impoſſible to imagine a ſpirit without liberty, as a body without extenſion. God himſelf could not diveſt a ſpirit of this eſſential property.

It is by this, accordingly, that we are enabled to ſolve

ſolve all the perplexing queſtions reſpecting the origin of evil, the permiſſion of ſin, and the exiſtence of all the calamities by which the world is oppreſſed; their great and only ſource is human liberty.

10th March, 1761.

LETTER CX.

Of the Origin and Permiſſion of Evil; and of Sin.

THE origin and permiſſion of evil in the world, is an article which has, in all ages, greatly perplexed theologians and philoſophers. To believe that God, a Being ſupremely good, ſhould have created this world, and to ſee it overwhelmed with ſuch variety of evil, appears ſo contradictory, that ſome found themſelves reduced to the neceſſity of admitting two principles, the one ſupremely good, the other ſupremely evil. This was the opinion entertaided by the ancient heretics, known in hiſtory by the name of *Manicheans*; who, ſeeing no other way of accounting for the origin of evil, were reduced to this extremity. Though the queſtion be extremely complicated, this ſingle remark, that liberty is a quality eſſential to ſpirits, diſpels, at once, a great part of the difficulties, which would otherwiſe be inſurmountable.

In truth, when God had created man, it was too late to prevent ſin, his liberty being ſuſceptible of no conſtraint. But, I ſhall be told, it would have been

been better not to create ſuch and ſuch men, or ſpirits, who, as God muſt have foreſeen, would abuſe their liberty, and plunge into ſin. I ſhould deem it rather raſh to enter upon this diſcuſſion, and to pretend to judge of the choice which God might have been able to make, in creating ſpirits; and, perhaps, the plan of the univerſe required the exiſtence of ſpirits of every poſſible deſcription. And, in fact, when we reflect, that not only our earth, but all the planets, are the habitations of rational beings; and that even all the fixed ſtars are ſuns, each of which may have around it a ſyſtem of planets, likewiſe habitable, it is clear, that the number of all the beings endowed with reaſon, which have exiſted, which do exiſt, and which ſhall exiſt, in the whole univerſe, muſt be infinite.

It is, therefore, unpardonable preſumption to inſinuate, that God ought not to have granted exiſtence to a great number of ſpirits; and the very perſons, who thus reproach their Maker, would certainly not wiſh to be of the number of thoſe to whom exiſtence was denied. This firſt objection, then, is ſufficiently done away; and it is no way inconſiſtent with the Divine perfections, that exiſtence has been beſtowed on all ſpirits, good and bad.

It is next alleged, that the miſchievouſneſs of ſpirits, or reaſonable beings, ought to have been repreſſed by the divine Omnipotence. On this I remark, that liberty is ſo eſſential to all ſpirits, as to be beyond all power of conſtraint; the only method of govern- ſpirits conſiſts in the uſe of motives, to diſpoſe them

them to what is good, and to diffuade them from evil; but, in this refpect, we find not the flighteft ground of complaint. The moft powerful motives have, undoubtedly, been propofed to all fpirits, to incline them to good, thefe motives being founded on their own falvation; but they by no means employ conftraint, for this would be contrary to their nature, and in all refpects impoffible.

However wicked men may be, it never can be in their power to excufe themfelves, from ignorance of the motives which would have prompted them to good: the divine law, which conftantly aims at their everlafting happinefs, is engraven on their heart, and it muft always be their own fault if they plunge into evil. Religion difcovers to us, likewife, fo many other means which God employs to reclaim us from our wanderings, that, on this fide, we may reft confidently affured, that God has omitted nothing which could have prevented the malignant explofions of men, and of other reafonable beings.

But thofe who bewilder themfelves in fuch doubts refpecting the origin and the permiffion of evil in the world, perpetually confound the corporeal with the fpiritual world; they imagine that fpirits are, as bodies, fufceptible of conftraint. Severe difcipline is, frequently, capable of preventing, among the children of a family, the foldiers of an army, or the inhabitants of a city, the open eruption of perverfe difpofitions; but it muft be carefully remarked, that this conftraint extends only to what is corporeal; it, in no refpect, reftrains the fpirit from being as

 vicious,

vicious, and as malignant, as if it enjoyed the moſt unbounded licence.

Human governments muſt reſt contented with this exterior, or apparent tranquillity, and give themſelves little trouble about the real diſpoſitions of men's minds; but, before God, the thoughts all lie open, and perverſe inclinations, however concealed from men, are as abominable in his ſight, as if they had broke out into the moſt atrocious actions. Men ſuffer themſelves to be dazzled by falſe appearances; but God has reſpect to the real diſpoſitions of every ſpirit, according as they are virtuous, or vicious, independently of the actions which flow from them.

The Holy Scriptures contain, to this purpoſe, the moſt pointed declarations, and inform us, that he who meditates only the deſtruction of his neighbour, ſuffering himſelf to be hurried away by a ſpirit of hatred, is as criminal in the ſight of God, as the actual murderer; and that he who indulges a covetous deſire of another's property is, in his eſtimation, as much a thief as he who really ſteals.

In this reſpect, therefore, the government of God over ſpirits, or rational beings, is infinitely different from that which men exerciſe over men like themſelves; and we greatly err, if we imagine that a government, which appears the beſt in the eyes of men, is really ſo in the judgment of God. This is a reflection of which we ought never to loſe ſight.

March, 1761.

LETTER

LETTER CXI.

Of moral and phyfical Evil.

WHEN complaint is made of the evil which prevails in the world, a diftribution of them into two claffes takes place: *moral evils* and *phyfical evils*. The clafs of moral evils contains the perverfe or vicious inclinations, the difpofitions of fpirits to what is evil or criminal, which is undoubtedly the moft grievous calamity and the greateft imperfection which can exift.

In truth, with regard to fpirits, it is impoffible to conceive a more deplorable irregularity, than when they deviate from the eternal laws of virtue, and abandon themfelves to the commiffion of vice. Virtue is the only means of rendering a fpirit happy; to beftow felicity on a vicious fpirit is beyond the power of God himfelf. Every fpirit addicted to vice is neceffarily miferable, and, unlefs it return to virtue, it's mifery cannot come to an end: fuch is the idea I form of demons, of wicked and infernal fpirits; an idea which, to me, appears confonant to what Scripture fuggefts on the fubject.

Infidels make a jeft of this; but as men cannot pretend to be the beft of all rational beings, neither can they boaft of being the moft wicked; there are, undoubtedly, beings much more depraved than the moft malignant of mankind, fuch as devils. But I have already made it appear, that the exiftence of fo many corrupted men and ſpirits, ought not to form any objection againſt the perfection of this world, much leſs be conſidered as an imputation of the Supreme Being.

A ſpirit, the devil not excepted, is always a being, excellent, and infinitely ſuperior to every thing that can be conceived in the corporeal world; and this world, as far as it contains an infinite number of ſpirits, of all orders, is always a work of the higheſt perfection. Now, all ſpirits being eſſentially free, criminality was poſſible from the commencement of their exiſtence, and could not be prevented even by the divine Omnipotence. Beſides, ſpirits are the authors of the evils which neceſſarily reſult from ſin, every free agent being always the only author of the evil which he commits; and, conſequently, theſe evils cannot be imputed to the Creator; as among men, the workman who makes the ſword is not reſponſible for the miſchief that is done with it. Thus, with reſpect to the moral evils which prevail in the world, the ſovereign goodneſs of God is ſufficiently juſtified.

The other claſs, that of *phyſical evils*, contains all the calamities and miſeries to which men are expoſed in this world. It is admitted, that moſt of theſe are a neceſſary conſequence of the malice, and other vicious propenſities with which men, as well as other ſpirits, are infected; but as theſe conſequences are communicated by means of bodies, it is aſked, Why God ſhould permit to wicked ſpirits, the power of acting ſo efficaciouſly on bodies, and of employing them

them as instruments to execute their pernicious purposes? A father, who saw his son on the point of committing a murder, would snatch the sword out of his hand, and prevent the perpetration of a crime so heinous. I have already observed, that this abandoned son is equally guilty before God, whether he has actually accomplished his design, or only made ineffectual efforts to execute it, and the father, who prevented him, does not thereby render him better.

We may, nevertheless, confidently maintain, that God does not permit a free course to the wickedness of man. Did nothing resist the execution of all the pernicious purposes of the human heart, how miserable should we be! We frequently see, that the wicked have great difficulties to encounter, and though they should succeed, they have no power over the consequences of their actions, which always depend on so many other circumstances, that, in the issue, they produce the directly opposite effect from what was intended. It cannot be denied, at the same time, that there may result from these, calamities and miseries to torment mankind; and it is imagined, that the world would be infinitely better governed, were God to interpose an effectual restraint to the wickedness and audacity of men.

It would, undoubtedly, be very easy for God to crush to death a tyrant, before he could realize his cruel and oppressive designs, or to strike dumb an unjust judge, who was going to pronounce an iniquitous sentence. We might then live quietly, and enjoy all the comforts of life, supposing God were to grant us the bleffings of health, and all the good things we could wifh for: our happinefs would thus be perfect. On this plan they would have the world governed, in order to render us all happy: the wicked difabled to perpetrate their criminal purpofes, and the good in poffeffion of the peaceful enjoyment of all the bleffings which they can defire.

It is believed, and with good reafon, that God wifhes the happinefs of men, and it is matter of furprize, that this world fhould be fo different from the plan which is imagined the moft proper for the attainment of this end. We rather fee the wicked frequently enjoying, not only all the advantages of this life, but put in a condition to execute their machinations, to the confufion and diftrefs of perfons of worth, while the good are oppreffed and overwhelmed by the moft fenfible evils, pains, difeafes, mortifications, lofs of goods, and, in general, by every fpecies of calamity; and that, at laft, the good as well as the bad, muft infallibly die, which appears to be the greateft of all evils.

Looking on the world in this point of view, one is tempted to call in queftion the fupreme wifdom and goodnefs of the Creator; but it is a hazard which we muft take great care to fhun.

17th March, 1761.

LETTER

LETTER CXII.

Reply to Complaints of the Exiſtence of phyſical Evil.

SUPPOSING our exiſtence limited to the preſent life, the poſſeſſion of the good things of this world, and the enjoyment of every delight, would be very far from filling up the meaſure of our happineſs. All are agreed, that true felicity conſiſts in mental tranquillity and ſatisfaction, which are ſeldom, if ever, accompanied with that brilliancy of condition, which is conſidered as ſuch an ineſtimable bleſſing, by thoſe who judge only from appearances.

The inſufficiency of temporal good things to render us happy, becomes ſtill more manifeſt, when we come to reflect on our real deſtination. Death does not put a period to our exiſtence, it rather tranſmits us into another life, which is to endure for ever. The faculties of our ſoul, and our attainments in knowledge, will then, no doubt, be carried to the higheſt perfection; and it is on this new ſtate that our real happineſs depends, and this ſtate cannot be happy without virtue.

The infinite perfections of the Supreme Being, which we now perceive only as through a thick cloud, ſhall then ſhine in the brighteſt luſtre, and ſhall become the principal object of our contemplation, admiration, adoration. There, not only ſhall our underſtanding find the moſt inexhauſtible ſtores of pure and perfect knowledge, but we ſhall be permitted to hope for admiſſion into favour with the Supreme Being, and to aſpire after the moſt endearing expreſſions of his love. How happy do we reckon the peculiar favourites of a great prince, eſpecially if he is really great, though the favours which he beſtows are marred by many infuſions of bitterneſs? What will it then be, in the life to come, when God himſelf ſhall *ſhed abroad his love in our hearts*, a love the effects of which ſhall never be interrupted nor deſtroyed! This ſhall, thenceforward, conſtitute a felicity infinitely ſurpaſſing all that we can conceive,

In order to a participation of theſe inexpreſſible favours, flowing from the love of the Supreme Being, it is natural that, on our part, we ſhould be penetrated with ſentiments of the moſt lively affection to him. This bleſſed union abſolutely requires, in us, a certain diſpoſition, without which we ſhould be incapable of participating in it; and this diſpoſition conſiſts in virtue, the baſis of which is the love of God, and that of our neighbour. The attainment of virtue, then, ſhould be our chief, our only object in this life, where we exiſt but for this end, to prepare for, and to render ourſelves worthy of partaking in ſupreme and eternal felicity.

In this point of view, we muſt form a judgment of the events which befall us in this life. It is not the poſſeſſion of the good things of this world that renders us happy; it is rather, a ſituation which moſt effectually conducts to virtue. If proſperity were the certain means of rendering us happy, we ight be ſuffered to complain of adverſity; but adverſity

versity may rather have the effect of confirming our virtue, and, in this view, all the complaints of men, respecting the physical evils of life, are, likewise, completely done away.

You have no difficulty, then, in comprehending, that God had the most solid reasons for admitting into the world so many calamities and miseries, as the whole obviously contributes to our salvation. It is unquestionably true, that these calamities are, for the most part, natural consequences of human corruption; but it is in this very thing, that we must principally admire the wisdom of the Supreme Being, who knows how to over-rule the most vicious actions, for our final happiness.

Many good people would not have reached such a sublimity of virtue, had they not been oppressed, and tormented, by cruelty and injustice.

I have already remarked, that bad actions are such, only with regard to those who commit them: the determination of their soul alone is criminal, the action itself being a thing purely corporeal, in as much as, considered independently of the person who commits it, there is nothing, either good or evil, in the case. A mason falling from the roof of a house upon a man, as certainly kills him as the most determined assassin. The action is absolutely the same; but the mason is not guilty in the slightest degree; whereas the assassin deserves the severest punishment. Thus, however criminal actions may be, with regard to those who commit them, we must consider them in quite a different light as they affect ourſelves, or produce an influence on our ſituation.

We ought, therefore, to reflect, that nothing can befall us, but what is perfectly conſonant to the ſovereign wiſdom of God. The wicked may be guilty of injuſtice towards us, but we cannot upon the whole ſuffer from it; no one can ever injure us, though he may greatly hurt himſelf; and in every thing that comes to paſs, we ought always to acknowledge God, as if it befell us immediately by his expreſs appointment. We may, moreover, reſt aſſured, that it is not from caprice, or merely to vex us, that God diſpoſes the events in which we are concerned, but that they muſt infallibly terminate in our true happineſs. Thoſe who conſider all events in this light, will ſoon have the ſatisfaction of being convinced, that God exerciſes a peculiar care over them.

21ſt March, 1761.

LETTER CXIII.

The real Deſtination of Man; Uſefulneſs and Neceſſity of Adverſity.

I HOPE you have no doubts remaining, with reſpect to this great queſtion: How the evils of this world can be reconciled to the ſupreme wiſdom and goodneſs of the Creator? The ſolution of it is inconteſtably founded on the real deſtination of man, and

and of other intelligent beings, whofe exiftence is not limited to this life. The moment that we lofe fight of this important truth, we find ourfelves involved in the greateft perplexity, and if man were created only for this life, it would affuredly be impoffible to eftablifh a confiftency between the perfections of God and the diftreffes and miferies with which this world is oppreffed. Thofe miferies would be but too real; and it were abfolutely impoffible to explain, How the profperity of the wicked, and the mifery of fo many good people, could confift with the divine juftice.

But no fooner do we reflect that this life is but the commencement of our exiftence, and that it is ferving as a preparation for one that fhall endure eternally, the face of things is entirely changed, and we are obliged to form a very different judgment of the evils with which this life appears to be overfpread. I have already remarked, that the profperity which we enjoy in this world is the reverfe of a fuitable preparation for a future life, and for rendering us worthy of the felicity which there awaits us. However important to our happinefs the poffeffion of the good things of this world may appear, this quality pertains to them only in fo far as they are impreffed with the fignatures of divine goodnefs, independent of which no earthly poffeffions could conftitute our felicity.

Real happinefs is to be found only in God himfelf; all other delights are but an empty fhade, and are capable of yielding only a momentary fatisfaction.

tion. Accordingly we see that those who enjoy them in the greatest abundance, are quickly satiated; and this apparent felicity serves only to inflame their desires, and to disorder their passions, by estranging them from the Supreme Good, instead of bringing them nearer to Him. But true felicity consists in a perfect union with God, which cannot subsist without a love and a confidence in his goodness, transcending all things: and this love requires a certain disposition of soul, for which we must be making preparation in this life.

This disposition is virtue, the foundation of which is contained in these two great precepts:

Thou shalt love the Lord thy God with all thy heart, with all thy soul, with all thy strength, and with all thy mind;

and the other, which is like unto it:

Thou shalt love thy neighbour as thyself.

Every other disposition of soul which deviates from these two precepts, is vicious, and absolutely unworthy to partake of true happiness. It is as impossible for a vicious man to enjoy happiness in the life to come, as for a deaf man to relish the pleasure of an exquisite piece of music. He must be for ever excluded from it, not by an arbitrary decree of God, but by the very nature of the thing; a vicious man not being, from his own nature, susceptible of supreme felicity.

If we consider the order and economy of the world, in this point of view, nothing can be more perfectly disposed for the attainment of this great end.

end. All events, the calamities themſelves which we undergo, are the moſt ſuitable means for conducting us to true happineſs: and in this reſpect, it may be with truth affirmed, that this is, indeed, the beſt world poſſible, as every thing in it concurs to promote our eternal ſalvation. When I reflect, that nothing befalls me by chance; but that every event is directed by Providence, in the view of rendering me truly and everlaſtingly happy, how ought this conſideration to raiſe my thoughts to God, and to repleniſh my ſoul with the pureſt affection!

But, however efficacious theſe means may be in themſelves, they exerciſe no force upon our minds, to which liberty is ſo eſſential, that no degree of conſtraint can poſſibly take place. Experience, accordingly, frequently demonſtrates that our attachment to the objects of ſenſe renders us too vicious to liſten to theſe ſalutary admonitions. Abuſe of the means which would have improved our virtue, plunges us deeper and deeper into vice, and hurries us aſide from the only path that leads to happineſs.

24th March, 1761.

LETTER

LETTER CXIV.

Of true Happineſs. Converſion of Sinners. Reply to Objections on the Subject.

THE holy life of the apoſtles, and of the other primitive Chriſtians, appears to me an irreſiſtible proof of the truth of the Chriſtian Religion. If true happineſs conſiſts in union with the Supreme Being, which it is impoſſible for a moment to doubt, the enjoyment of this happineſs neceſſarily requires, on our part, a certain diſpoſition, founded on ſupreme love to God, and the moſt perfect charity toward our neighbour, ſo that all thoſe who are deſtitute of this diſpoſition, deſtroy their own pretenſions to celeſtial felicity; and wicked men are, from their very nature, neceſſarily excluded from it, it being impoſſible for God himſelf to render them happy. For the Divine Omnipotence extends only to things which are in their nature poſſible, and liberty is ſo eſſential to ſpirits, that no degree of conſtraint can take place with reſpect to them.

It is only by motives, therefore, that ſpirits can be determined to that which is good: now what iotives could be propoſed to the apoſtles and other ſples of Jeſus Chriſt, to embrace a virtuous life, : powerful than the inſtructions of their divine :r, his miracles, his ſufferings, his death and reion, of which they were witneſſes. All theſe events, united to a doctrine the moſt ſublime,

blime, muſt have excited, in their hearts, the moſt fervent love and the moſt profound veneration for God, whom they could not but conſider and adore as at once their heavenly Father, and the abſolute Lord of the whole univerſe. Theſe lively impreſſions muſt neceſſarily have ſtifled in their breaſts every vicious propenſity, and have confirmed them, more and more, in the practice of virtue.

This ſalutary effect on the minds of the apoſtles, has nothing in it, of itſelf, miraculous, or which encroaches, in the ſmalleſt degree, on their liberty; though the events be ſupernatural. The great requiſite was, ſimply, a heart docile and uncorrupted by vice and paſſion. The miſſion, then, of Jeſus Chriſt into the world, produced, in the minds of the apoſtles, this diſpoſition, ſo neceſſary to the attainment and the enjoyment of ſupreme happineſs; and that miſſion ſtill ſupplies the ſame motives to purſue the ſame end. We have only to read attentively, and without prejudice, the hiſtory of it, and ſeriouſly to meditate on all the events.

I confine myſelf to the ſalutary effects of our Saviour's miſſion, without preſuming to dive into the myſteries of the work of our redemption, which infinitely tranſcend the powers of human underſtanding. I only remark, that theſe effects, of the truth of which we are convinced by experience, could not be produced by illuſion, or human impoſture; they are too ſalutary not to be divine. They are likewiſe perfectly in harmony with the inconteſtable principles which

which we have laid down, that ſpirits can be governed only by motives.

Theologians have maintained, and ſome ſtill maintain, that converſion is the immediate operation of God, without any co-operation on the part of man. They imagine that an act of the Divine will is ſufficient to transform, in an inſtant, the greateſt miſcreant into a virtuous man. Theſe good gentlemen may mean extremely well, and conſider themſelves as thus exalting the divine Omnipotence; but this ſentiment ſeems to me inconſiſtent with the juſtice and goodneſs of God, even though it were not ſubverſive of human liberty. How, it will with reaſon be ſaid, if a ſimple exertion of the divine Omnipotence is ſufficient for the inſtantaneous converſion of every ſinner, can it be poſſible that the decree ſhould not actually paſs, rather than leave ſo many thouſands to periſh, or employ the work of redemption, by which a part only of mankind is ſaved? I acknowledge that this objection appears to me much more formidable than all thoſe which infidelity raiſes againſt our holy religion, and which are founded entirely in ignorance of the true deſtination of man; but, bleſſed be God, it can have no place in the ſyſtem which I have taken the liberty to propoſe.

Some divines will perhaps accuſe me of hereſy, as if I were maintaining that the power of man is ſufficient for his converſion; but this reproach affects not, as I am conſcious of intending to place the lneſs of God in it's cleareſt light. In the work

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of converſion, man makes perfect uſe of his liberty, which is unſuſceptible of conſtraint, but man is always determined by motives. Now, theſe motives are ſuggeſted by the circumſtances and conjunctures of his condition. They depend entirely on divine Providence, which regulates all events, conformably to the laws of ſovereign wiſdom. It is God, therefore, who places men every inſtant in circumſtances the moſt favourable, and from which they may derive motives the moſt powerful, to produce their converſion; ſo that men are always indebted to God for the means which promote their ſalvation.

I have already remarked, that however wicked the actions of men may be, they have no power over their conſequences, and that God, when he created the world, arranged the courſe of all events, ſo that every man ſhould be every inſtant placed in circumſtances to him the moſt ſalutary. Happy the man who has wiſdom to turn them to good account!

This conviction muſt operate in us the happieſt effects: unbounded love to God, with a firm reliance on his providence, and the pureſt charity toward our neighbour. This idea of the Supreme Being, as exalted as it is conſolatory, ought to repleniſh our hearts with virtue the moſt ſublime, and effectually prepare us for the enjoyment of life eternal.

28th. March, 1761.

LETTER

LETTER CXV.

The true Foundation of human Knowledge. Sources of Truth, and Classes of Information derived from it.

HAVING taken the liberty to lay before you my opinion respecting the most important article of human knowledge, I flatter myself it will be sufficient to dissipate the doubts which naturally arise out of the subject, from want of exact ideas of the liberty of spirits.

I shall now have the honour of submitting to your consideration the true foundation of all our knowledge, and the means we have of being assured of the truth and certainty of what we know. We are very far from being always certain of the truth of all our sentiments; for we are but too frequently dazzled
urances, sometimes exceedingly slight, and
hood we afterwards discover. As we are,
continually in danger of deceiving our-
easonable man is bound to use every effort
or, though he may not always be so
succeed.

to be here chiefly considered is the so-
proofs on which we found our persua-
ruth whatever, and it is absolutely ne-
we should be in a condition to judge if
fficient to convince us or not. For this
ark, first, that all truths within our reach
are

are referable to three classes, essentially distinguished from each other.

The first contains the truths of the senses; the second, those of the understanding; and the third, those of belief. Each of these classes requires peculiar proofs of the truths included in it, and in these three classes all human knowledge is comprehended.

Proofs of the first class are reducible to the senses, and are thus expressed:

This is true, for I saw it, or am convinced of it by the evidence of my senses.

It is thus I know that the magnet attracts iron, because I see it, and experience furnishes me with incontestable proofs of the fact. Truths of this class are called *sensible*, because they are founded on the senses, or on experience.

Proofs of the second class are founded in ratiocination; thus:

This is true, for I am able to demonstrate it on principles of just reasoning, or by fair syllogisms.

To this class, principally, logic is to be referred, which prescribes rules for reasoning consequentially. It is thus, we know, that the three angles of a rectilineal triangle are together equal to two right angles. In this case I do not say I see it, or that my senses convince me of it; but I am assured of it's truth by a process of reasoning. Truths of this class are called *intellectual*, and here we must rank all the truths of geometry, and of the other sciences, in as much as they are supported by demonstration. You must be sensible, that such truths are wholly different from thoſe of the firſt claſs, in ſupport of which we adduce no other proofs but the ſenſes, or experience, which aſſure us that the fact is ſo, though we may not know the cauſe of it. In the example of the magnet, we do not know how the attraction of iron is a neceſſary effect of the nature of the magnet, and of iron; but we are not the leſs convinced of the truth of the fact. Truths of the firſt claſs are as certain as thoſe of the ſecond, though the proofs which we have of them are entirely different.

I proceed to the third claſs of truths, that of faith, which we believe, becauſe perſons worthy of credit relate them; or when we ſay:

This is true, for ſeveral creditable perſons have aſſured us of it.

This claſs, accordingly, includes all *hiſtorical truths.* You believe, no doubt, that there was formerly a king of Macedon, called Alexander the Great, who made himſelf maſter of the kingdom of Perſia, though you never ſaw him, and are unable to demonſtrate, geometrically, that ſuch a perſon ever exiſted. But we believe it on the authority of the authors, who have written his hiſtory, and we entertain no doubt of their fidelity. But may it not be poſſible that theſe authors have concerted to deceive us? We have every reaſon to reject ſuch an inſinuation, and we are as much convinced of the truth of theſe facts, at leaſt of a great part of them, as of truths of the firſt and ſecond claſſes.

The proofs of theſe three claſſes of truths are extremely different; but if they are ſolid, each in it's kind,

ind, they muſt equally produce conviction: You annot poſſibly doubt that Ruſſians and Auſtrians ave been at Berlin, though you did not ſee them: his, then, is to you a truth of the third claſs, as you elieve it on the report of others; but to me it is ne of the firſt claſs, becauſe I ſaw them, and converſed with them, and as many others were aſſured of their preſence by means of other ſenſes. You ave, nevertheleſs, as complete conviction of the fact s we have.

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END OF THE FIRST VOLUME.

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