AN

INTRODUCTION

TO

ASTRONOMY.

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AN

INTRODUCTION

TO

ASTRONOMY.

IN A

SERIES OF LETTERS,

FROM A

PRECEPTOR TO HIS PUPIL.

IN WHICH THE MOST USEFUL AND INTERESTING PARTS OF THE SCIENCE ARE CLEARLY AND FAMILIARLY EXPLAINED.

ILLUSTRATED WITH COPPER-PLATES.

BY JOHN BONNYCASTLE,

PROFESSOR OF MATHEMATICS IN THE ROYAL MILITARY ACADEMY, WOOLWICH.

THE SEVENTH EDITION,

CORRECTED, AND GREATLY IMPROVED.

.... Docuit quæ maximus Atlas.
Hic canit errantem Lunam, Solisque labores. VIRGIL.

Into the heav'n of heav'ns I have presumed,
An earthly guest, and drawn empyreal air. MILTON.

LONDON:

PRINTED FOR J. NUNN; LAW AND WHITTAKER; CADELL AND DAVIES; LONGMAN, HURST, REES, ORME AND CO.; J. RICHARDSON; J. MAWMAN; BALDWIN, CRADOCK, AND JOY; GALE AND FENNER; AND J. ROBINSON.

1816.

PREFACE.

At a time when the sciences are generally cultivated, and a love of literature and knowledge has pervaded every rank and order of society, an easy and familiar account of the most interesting parts of Astronomy, will, it is presumed, be found an acceptable performance. Many, who are not sufficiently acquainted with the Mathematics, to read, with satisfaction, the works of Newton, and other eminent writers upon this subject, are yet very desirous of obtaining such an idea of it, as will enable them to comprehend the leading principles upon which it is founded, and to partake of those pleasures, which enquiries into Nature, and the investigation of some of her most sublime operations, must necessarily afford to every ingenuous and inquisitive mind.

To this class of readers, the following Letters are particularly addressed. They were at first designed for the private use of an individual, without any immediate view to publication; but as nothing of the kind, sufficiently clear and explicit to answer the purpose of general information, had hitherto appeared in our language, the author was induced to make them public, in hopes of their affording some information to those, whose situations in life, or confined education, may have prevented them from applying to a subject, which has commonly been thought of so abstruse and difficult a nature, as to be utterly unattainable without a previous knowledge of many other branches of science.

The principal object in view, throughout the whole performance, has been to avoid, as much as possible, all complicated mathematical principles and calculations, and to elucidate the most striking particulars, in as popular and easy a manner as the nature of the subject would admit. For this purpose, such parts of the science only have been chosen, as seemed most likely to excite the curiosity and attention of the uninformed reader; and to give him a taste for those studies and pursuits, which, besides the practical advantages they afford in some of the most important concerns of life, are of the greatest utility in forming and directing the mind, and in inculcating those liberal and enlarged ideas, which exalt and dignify the human character.

In a performance of this kind, which, from the nature of the undertaking, must be unavoidably deficient in many particulars, it is not to be expected that a scrupulous exactness has been always observed, or that every illustration of a subject is strictly mathematical. Such a minute attention would have been incompatible with the plan of the work, and extremely difficult to have been observed, if not altogether impossible. The chief design was to give a general idea of the operations and phænomena of nature, independently of abstruse reasoning or laborious calculations; and though, by this means, the knowledge obtained by the reader must, in some instances, be necessarily superficial, yet it may serve to give him proper ideas of the subject, and to correct those notions which the prejudices of education, or the apparent view of things, might suggest.

It may also be observed, that as the work is designed chiefly for the purpose of popular instruction, the author has not scrupled to make a free use of the labours of preceding writers, whenever he found any particular subject illustrated in a manner suitable to his design: and if he has not always acknowledged his obligations, it is because such alterations were commonly made as rendered it impossible, without a show of exactness which would have appeared affected and pedantic. The new matter introduced in every part of the performance, where it was most wanted, and the pains that have been taken to arrange and methodize the whole, are, it is hoped, sufficient to obviate every objection which may be made on this account.

The frequent allusions to the Poets, and the various quotations interspersed throughout the work, are intended as an agreeable relief to minds unaccustomed to the regular deduction of facts by mathematical reasoning, and to enliven those parts where a simple detail of particulars must, from its necessary length, become languid. Poetical descriptions, though they may not be strictly conformable to the rigid principles of the science they are meant to elucidate, generally leave a stronger impression on the mind, and are far more captivating than simple unadorned language. From a persuasion of this kind, the author has sometimes expatiated on subjects with a warmth of expression, that may perhaps seem too florid for a philosophical performance; but which alone could delineate those elevated ideas, that must necessarily arise in the contemplation of some of the grandest scenes in nature, and the most stupendous works of creation.

ADVERTISEMENT

TO THE SEVENTH EDITION.

The favourable reception which the various editions of this performance have met with from the public has induced the author to undertake an entire revision of every part of the work, and to make such alterations, amendments and additions, as, upon a careful re-consideration of the subject, appeared to be wanting.

Since the time of its first publication, four additional planets, belonging to our system, have been discovered, and many important improvements have been made in several branches of the science; which it became necessary to notice. This has accordingly been done, in a manner which it is hoped will render the work as satisfactory and complete, as the popular plan that was first adopted, will admit.

Royal Military Academy, Woolwich,
June 24, 1816.

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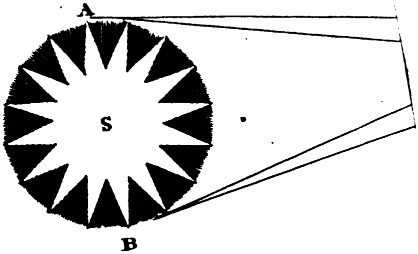
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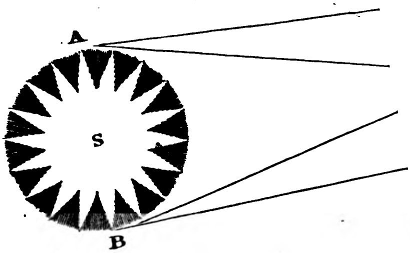
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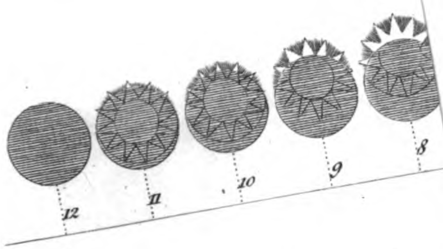
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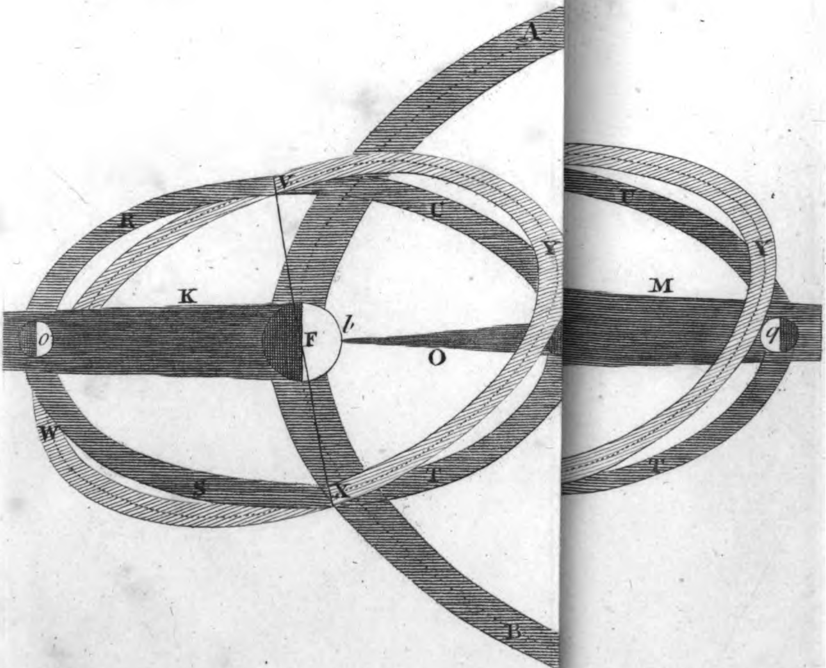
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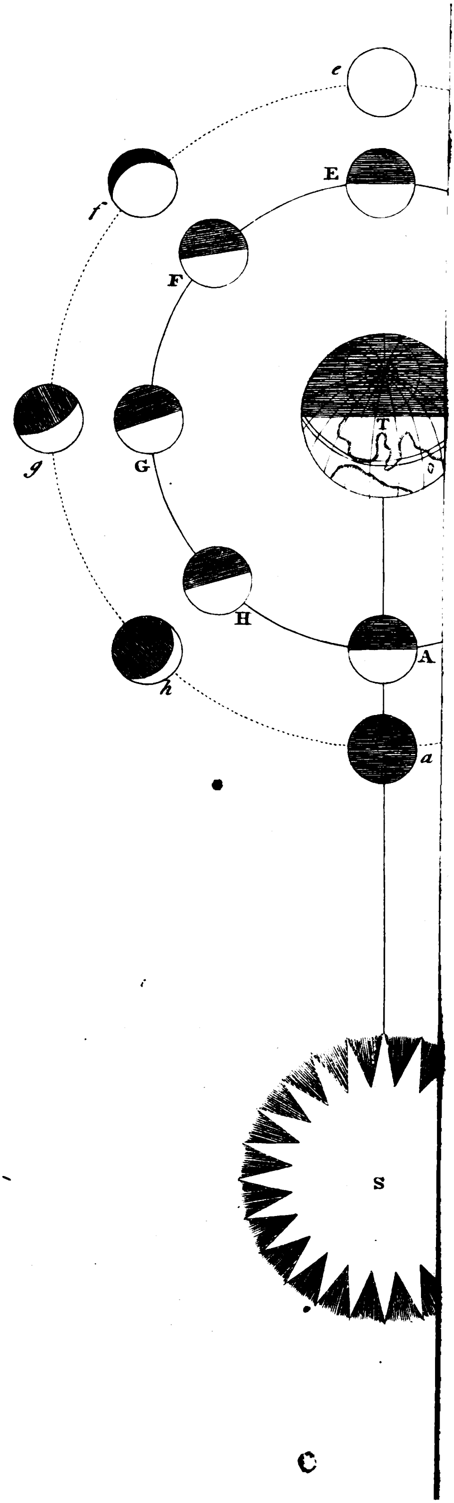
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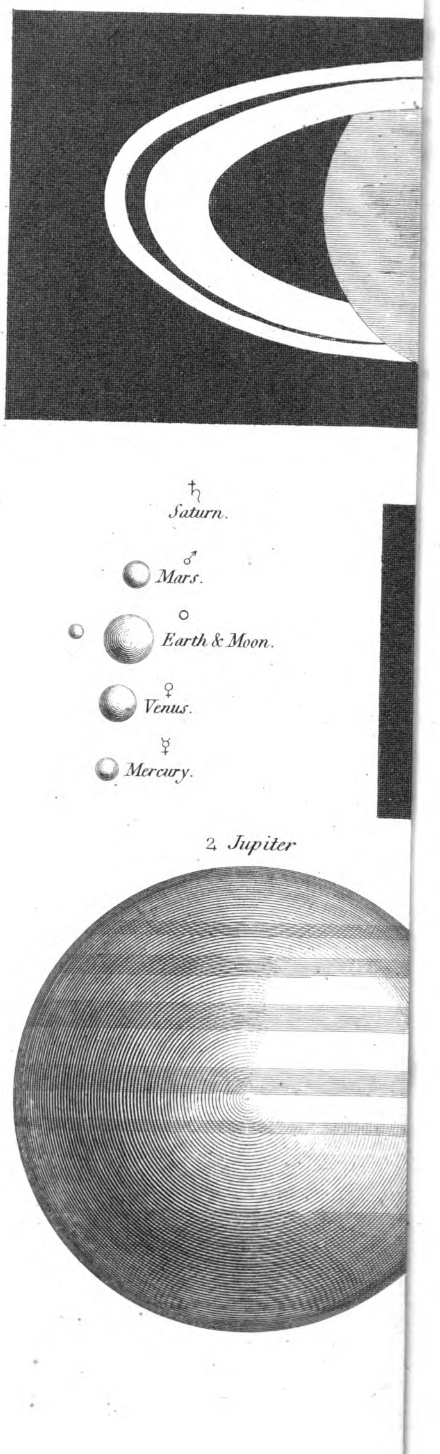

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Mercury.
♃ Jupiter

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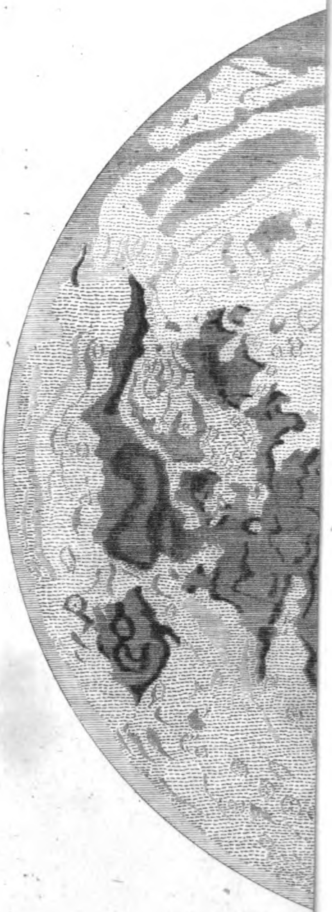

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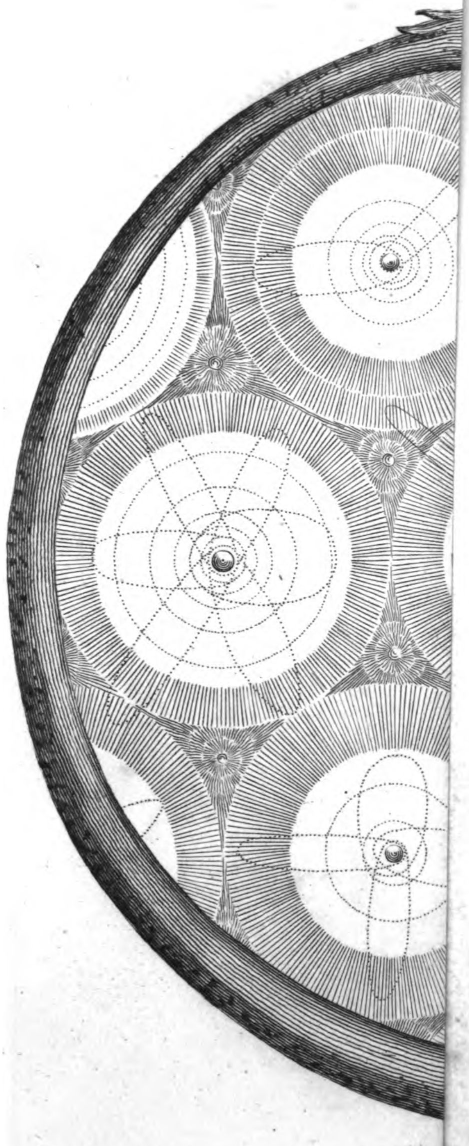
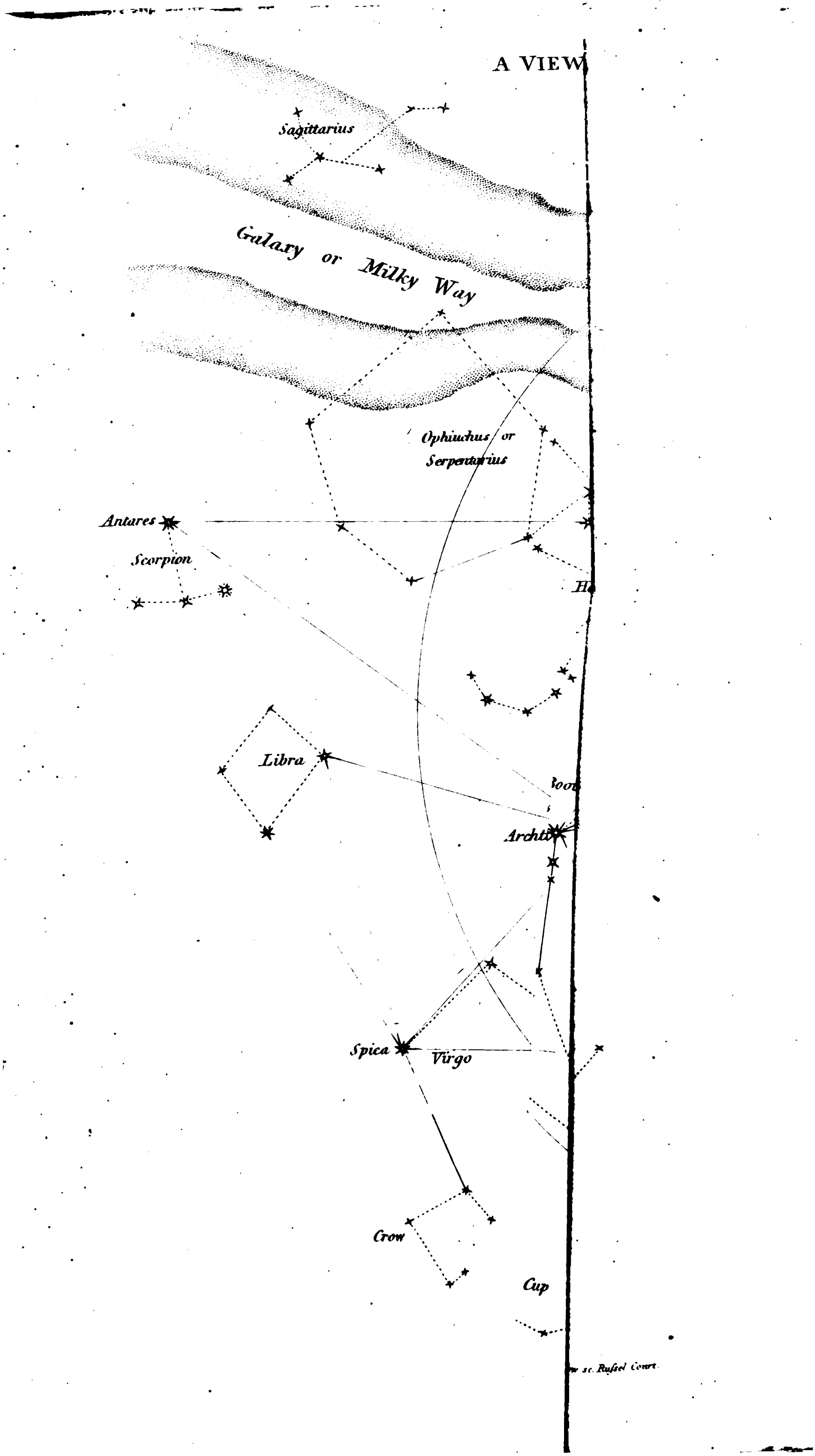
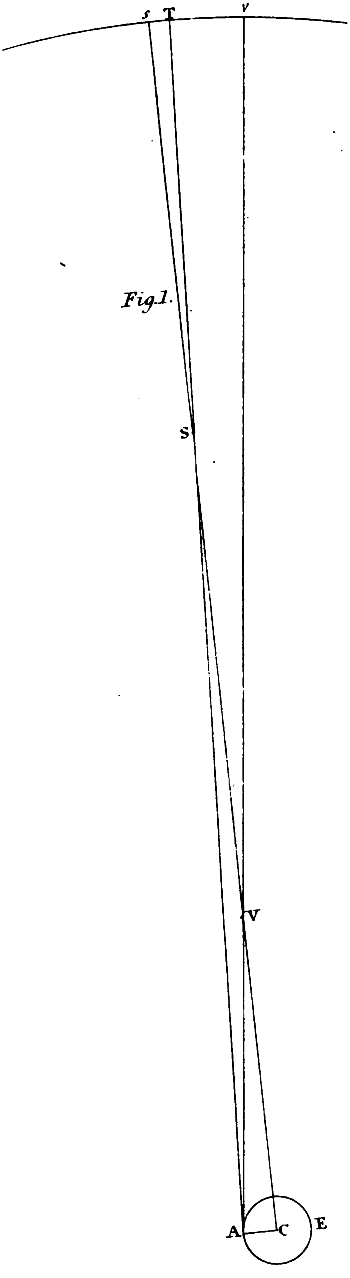




A VIEW
Sagittarius
Galaxy or Milky Way
Ophiuchus or
Serpentarius
Antares
Scorpion
Libra
Archt
Spica
Virgo
Crow
Cup

Pl. XIII.



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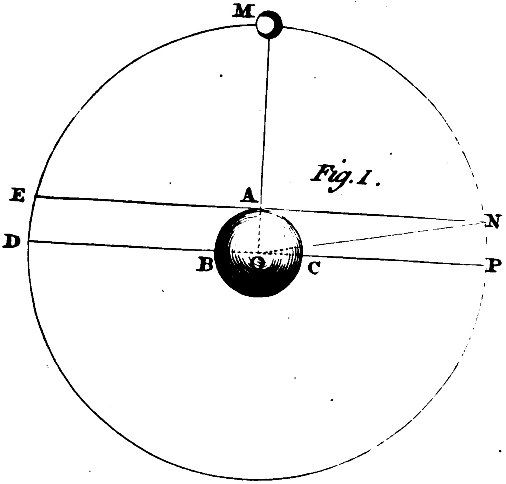

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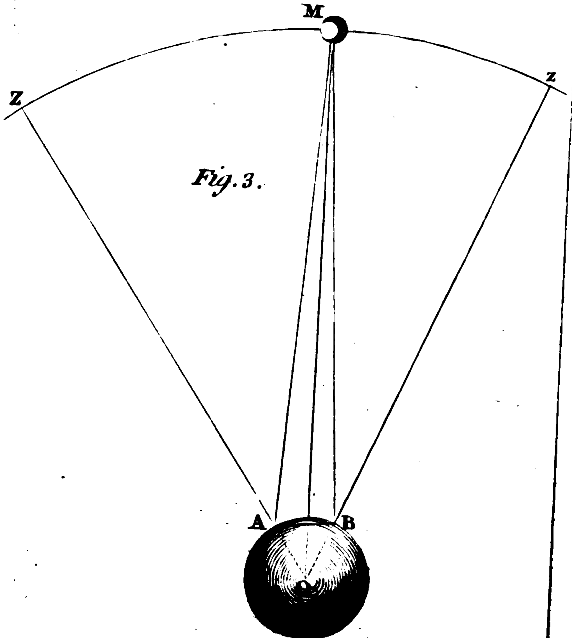

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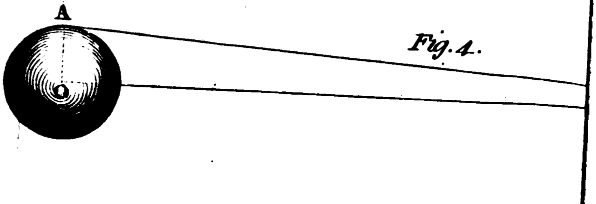

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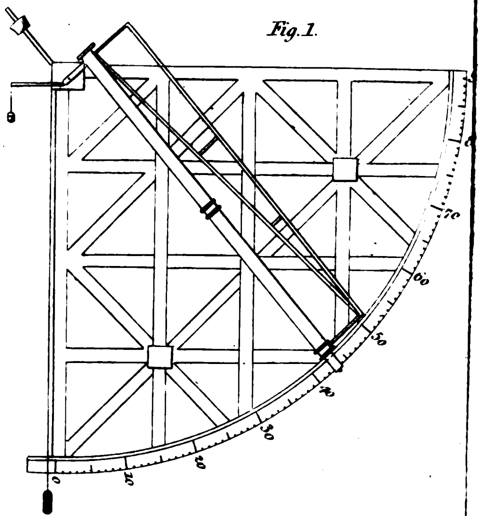

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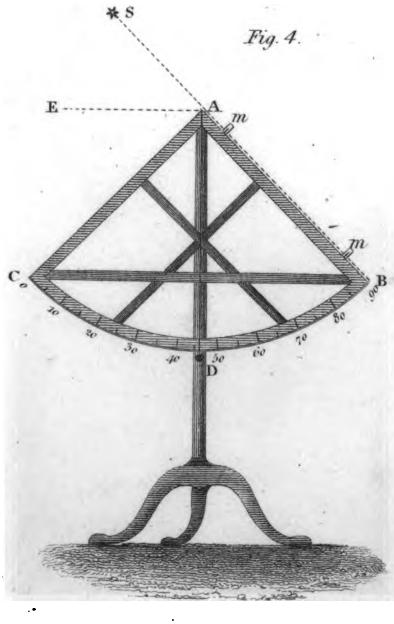

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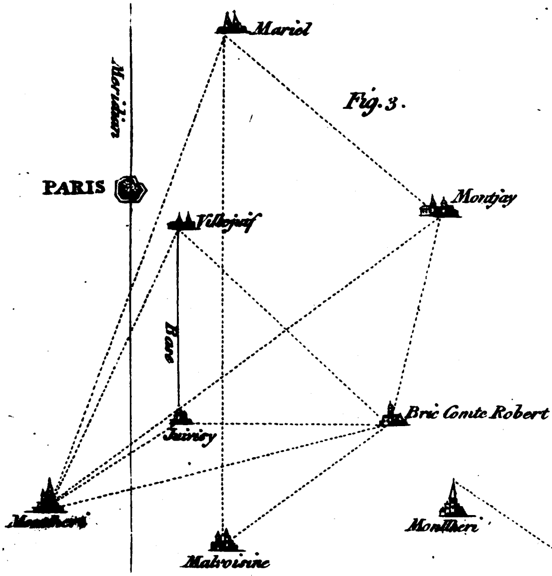

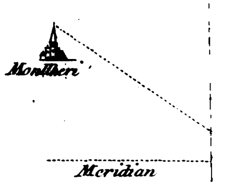

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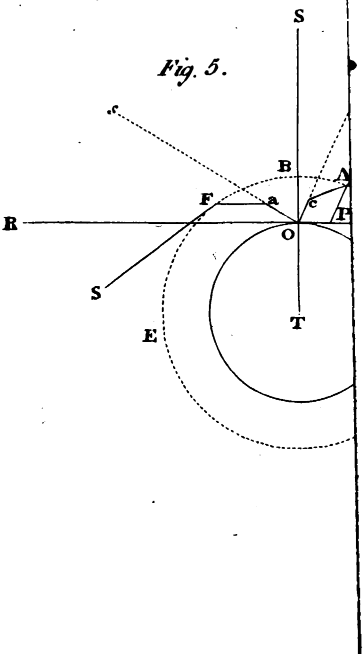

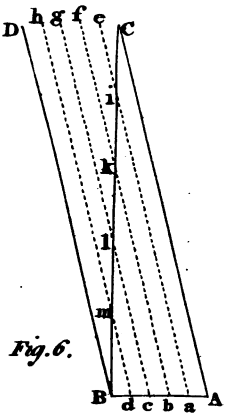

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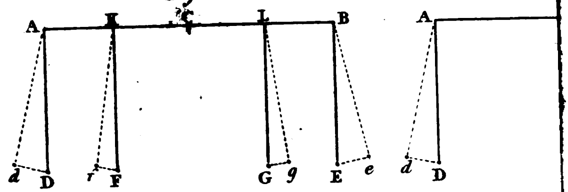

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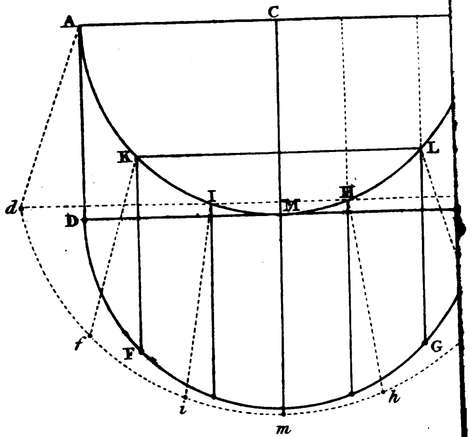

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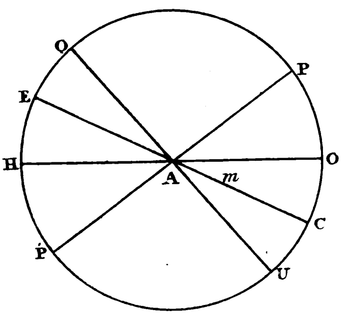

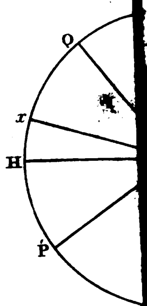

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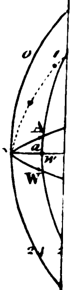

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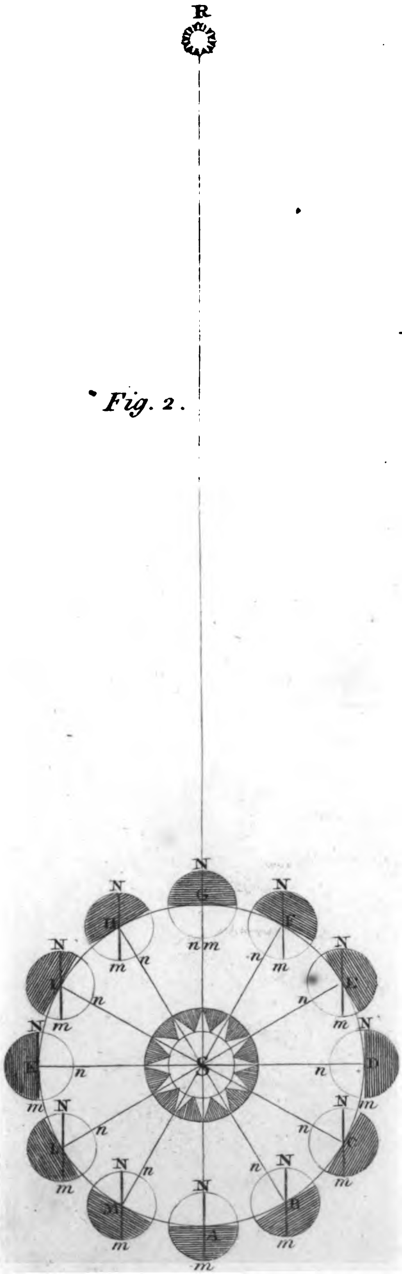

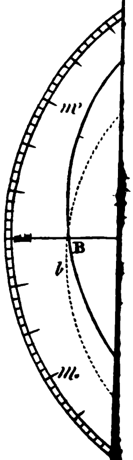

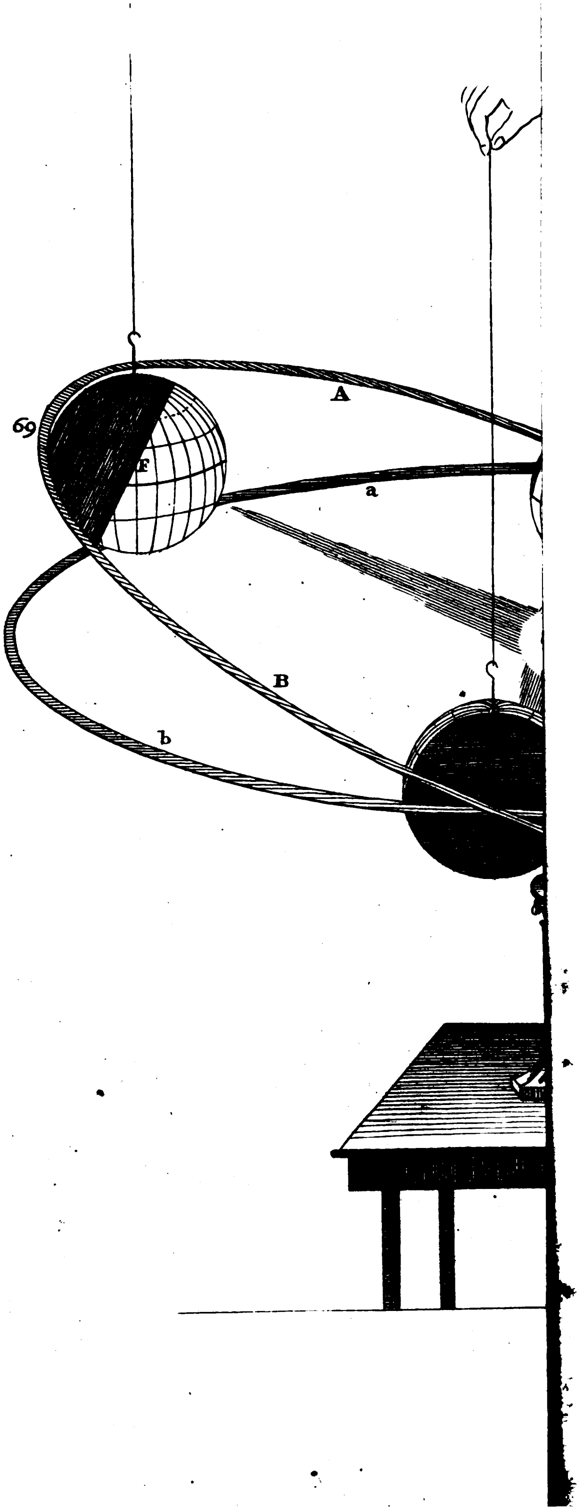
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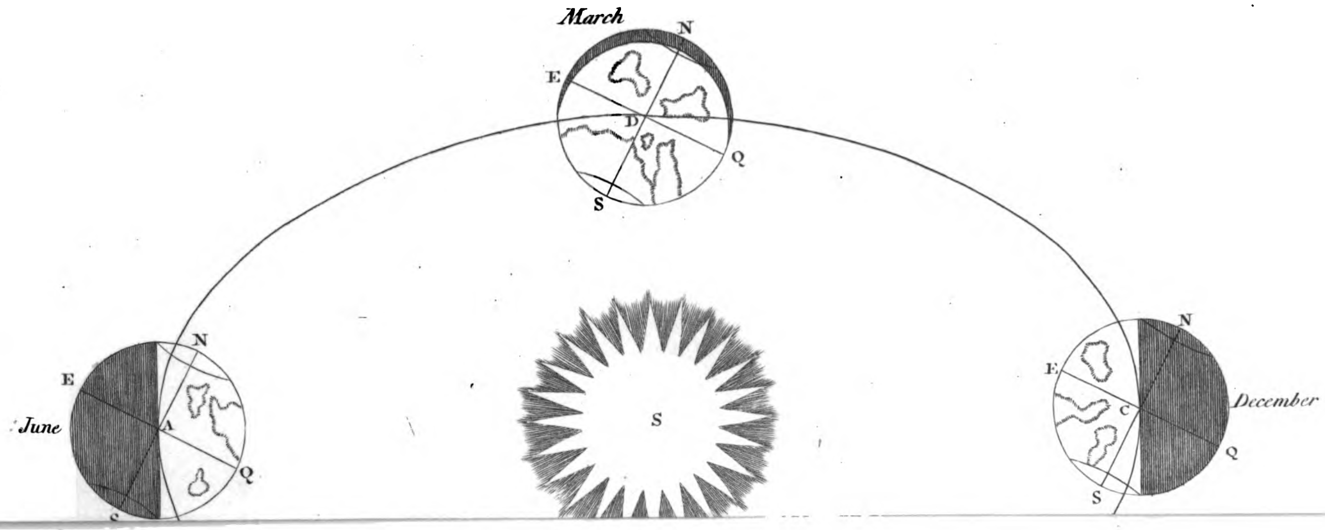
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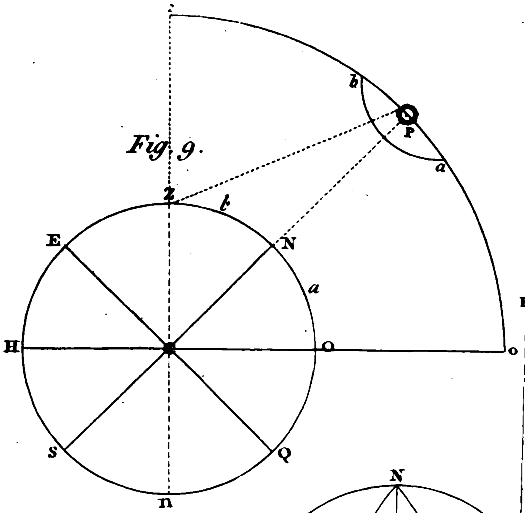

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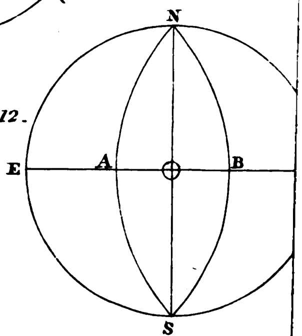

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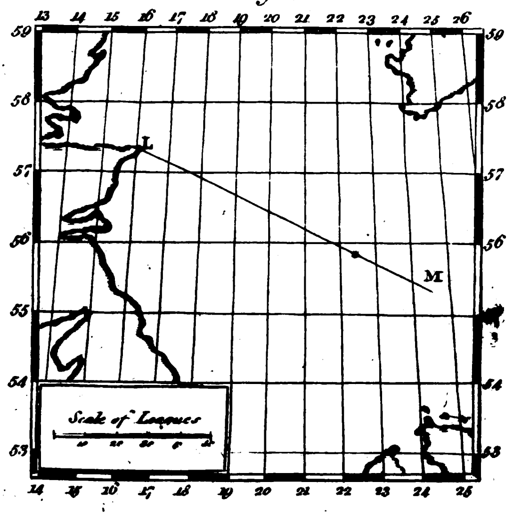

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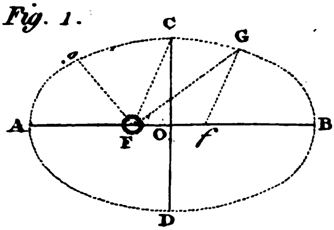

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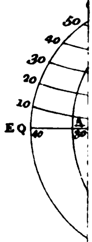

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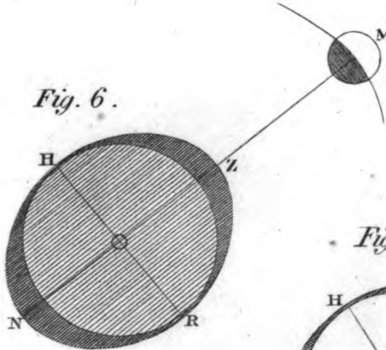

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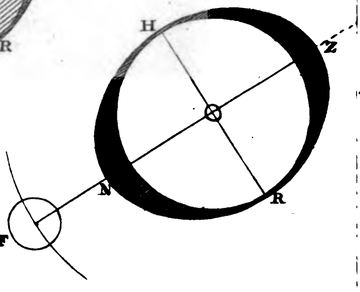

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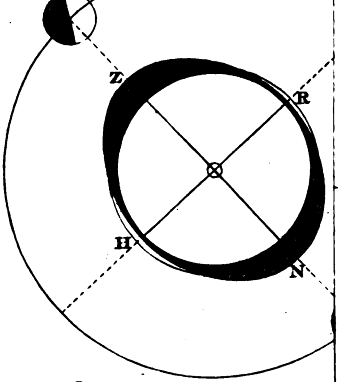
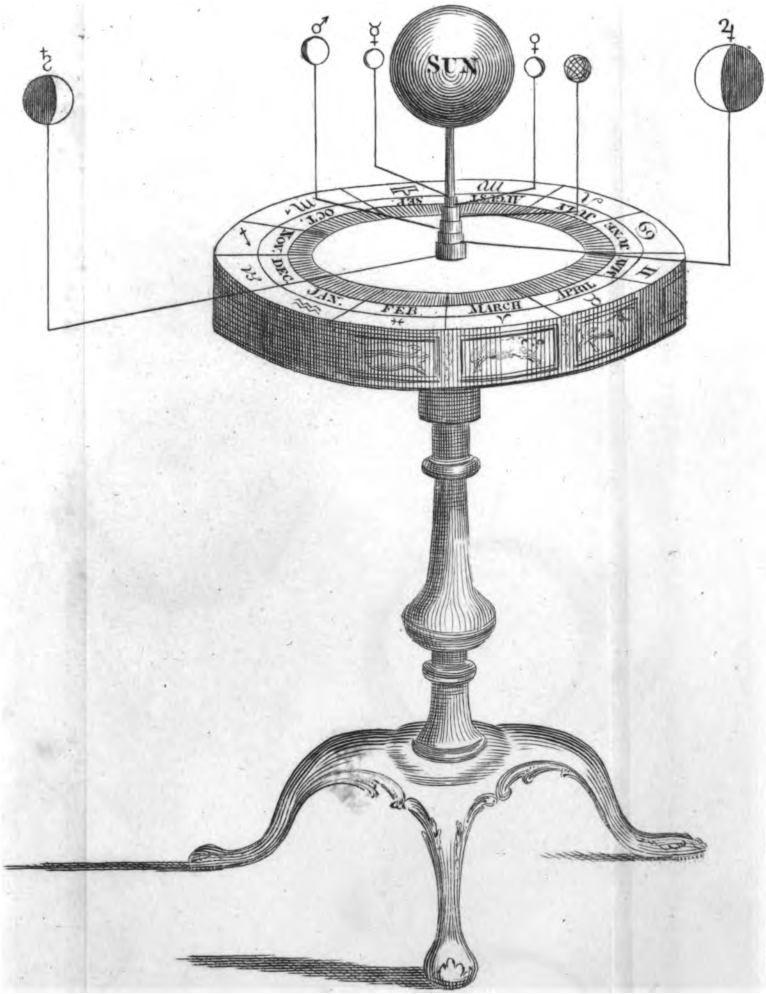


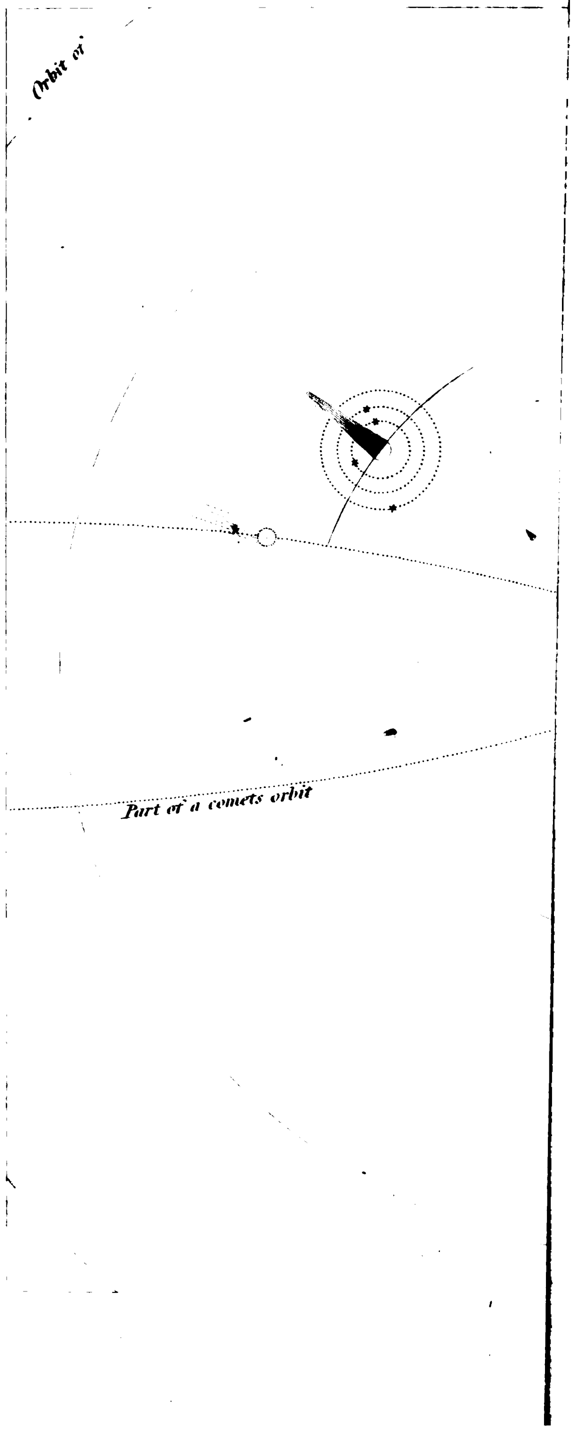


A PLANETARIUM,

Shewing the various Phænomena of the

Solar System.

A VIEW



LETTER I.

OF THE USE AND ADVANTAGE OF ASTRONOMY.

DEAR SIR,

I HAVE always loved the sciences for their own sake, but I now wish to cultivate them for yours. You have convinced me, by your amiable and polite manners, that your mind is formed for the acquisition of truth and knowledge; and if I can afford you any assistance, in directing your studies and pursuits, I shall consider it as the most agreeable employment of my life.

The mode of communication you propose, is, I am afraid, less favourable to improvement, than your partiality in my favour will suffer you to imagine; but as our different situations and engagements deny me the pleasure of a personal intercourse, I shall be happy to promote your views, and contribute to your information, by every means in my power.

Astronomy seems to be the science you are desirous of being first acquainted with; and I know not that you could have made a better choice. This subject will awaken every faculty of your mind, and is, of all others, the best calculated to to excite your curiosity and admiration. Not that I would wish to engage you in long calculations and laborious enquiries, which are of use chiefly to the practical proficient, who makes this the principal object of his pursuit; but there is a general knowledge of the most interesting particulars, which is so easily obtained, that it is inexcusable for a person of a liberal education to be totally destitute of it.

It is this pleasing part of the science that I would at present recommend to your attention: and as you are but little acquainted with mathematical principles, I shall endeavour to treat of it in as easy and independent a manner as the nature of the subject will admit. To divest it entirely of its usual terms would be a vain and ridiculous attempt; but, if I do not deceive myself, I shall be able to remove every obstacle of this kind which is likely to impede your progress, or prevent your improvement.

Not to detain you, therefore, by entering into a long dissertation on its origin and progress, which, at present, would be foreign to our purpose, I shall proceed immediately to the subject itself, and leave those particulars to be mentioned in their proper places. It will be sufficient to observe, that Astronomy is a science of the earliest antiquity, and has challenged the admiration of all ages. Poets, philosophers, and historians, have all given it their highest encomiums, and both kings and princes have enriched it with their labours.

The poets, in particular, have been lavish in their praises upon this subject, and are indebted to it for some of their boldest images, and most exalted descriptions. Virgil, the greatest master of verse after Homer, speaks of it with enthusiasm; and, in the second book of his Georgics, breaks out into this animated apostrophe:

"Ye sacred muses, with whose beauty fired,
My soul is ravish'd, and my brain inspired:
Whose priest I am, whose holy fillets wear;
Would you your poet's first petition hear;
Give me the ways of wand'ring stars to know;
The depths of heaven above, and earth below.
Teach me the various labours of the moon,
And whence proceed th' eclipses of the sun.
Why flowing tides prevail upon the main,
And in what dark recess they shrink again.
What shakes the solid earth, what cause delays
The summer nights, and shortens winter days."

DRYDEN'S VIRG.

In like manner, also, the wisest and greatest of men, both amongst the ancients and moderns, have confessed themselves charmed with the beauties of this science. To contemplate the grand spectacle of the heavens, has ever been considered as the noblest privilege of our nature. For it is here that we discover the wonders of the Almighty, and see the wisdom of God in the works of the creation. Nor is there any knowledge, attained by the light of nature, that gives us juster ideas of this great Being, or furnishes us with stronger arguments by which to demonstrate his existence and attributes. "The heavens," says the Psalmist, "declare the glory of God, and the firmament showeth his handywork; day unto day uttereth speech, and night unto night showeth knowledge; and there is no speech or language where their voice is not heard."

Thus astronomy is not only valuable, as it affords us such exalted ideas of the Deity and his works; but it also improves the mind, and increases the force and penetration of the human understanding. For, by means of this science, we are taught to discover the spring and fountain of all the celestial motions; to follow the footsteps of the Creator through the immense regions of his empire; and to trace the secret causes by which he regulates the great machine of the universe.

Were a knowledge of this kind attended with no other advantage, it has rendered essential service to humanity, by dissipating our vain fears and superstitious opinions. Man is naturally timid, and terrified at dangers which he cannot foresee. Before he is familiarized with nature he suspects her constancy, and regards all her operations with dread and apprehension. The regular and invariable order of things will, at length, inspire him with confidence; but still there are some singular phænomena, which appear as alarming exceptions to the general rule.

Thus, in the early ages of the world, ere men had learnt to judge of effects by their causes, a total eclipse of the sun or moon, was regarded with the utmost consternation, as seeming to portend the annihilation of the universe; and the comet, with his fiery tail and blazing hair, was considered as the harbinger of divine vengeance; whose appearance denounced the death of princes, the destruction of empires, famine and pestilence. But these opinions, as distressing as they were erroneous, are, at length, entirely exploded; and we are now taught, by Astronomers, to look upon comets and eclipses with tranquillity and compo sure.

Astrology is another malady of weak minds, which is effectually eradicated by the principles of this science. We now explore the heavens for the purpose of administering to our wants and necessities by useful discoveries, and not under the vain pretence of searching into the secret designs of fate, and the hidden events of futurity. This fallacious art, which appears so captivating to the vulgar, would have been as fatal to our peace, as it is contrary to the nature of things. Unhappy in the past, and dissatisfied with the present, we live only by the hope of what is to come. A knowledge of our future destiny, would serve only to increase the weight of our present afflictions; and by destroying every motive for exertion and activity, would render existence a misery, and the creation a desert.

But, notwithstanding the absurdity of its doctrines, this art is still practised in almost every country of the world: and it is not long since, that, even in Europe itself, the people had their cunning men, and the princes their astrologers, by whose predictions they regulated their most important concerns. It is the light of science only that can free us from the gross impositions of these wretched empirics. The immense distance of the stars is a convincing proof that they are too remote from us, for their influence to have any effect upon our globe. And as their aspects and conjunctions have been subject, from all eternity, to invariable laws, they must be totally insufficient to account for that infinite diversity of characters and passions which we observe among men. To make every event depend upon the twinkling of a star, is an absurdity equal to that of the Lapland witches, who pretend to regulate the course of the winds by tying knots in a string.

Another singular service which astronomy has rendered to society, is the assistance it affords to the husbandman and labourer, in the cultivation of the earth. The principal business of agriculture depends upon a knowledge of the seasons, and the course of the sun. In every climate there are certain necessary intervals between the various operations of tillage and culture; and these intervals, being once known by experience, point out the proper time when every operation is to be performed. But how are we to know exactly, and before-hand, as is often required, the commencement of every season, and its stated continuance? This can only be done by searching in the heavens for some invariable signs, which are always connected with them, and announce their return.

These signs are indicated by the sun, or some particular star; and though the knowledge of them is but little attended to at present, it was absolutely necessary in the ancient world, when the peasant had no other guide to direct his labours than his own observations. Thus Arcturus, Orion, and the Pleiades, marked out the several seasons of the Greeks; and the rising of Sirius with the sun, announced to the Egyptians the overflowing of the Nile, and the customary time of sowing their grain, which was immediately after its retreat. Many of the ancient poets and historians furnish us likewise with instances of a similar kind, from which it appears, that some of the most powerful and polished nations had, for a long time, no other calendar than that which consisted of a few simple observations on the rising and setting of certain stars.

In most of the common affairs of life, nothing is more necessary than an exact measure of time; but how is this to be obtained? We have the idea of succession only from motion; and in order that the division of it into parts may be accurate, it is requisite that the motion should be constant and uniform: but such a perfect and immutable test is not to be found upon the earth. Man has in himself the principles of motion; his sensations and ideas succeed each other in a certain order; but their durations and returns are so irregular, that he can, by no means, employ them as a proper measure of time. The mind that suffers, and the mind that rejoices; the criminal upon the rack, and the lover courting his mistress, compute by very different reckonings.

It is to the heavens alone that we must look for a certain and invariable standard. Those magnificent bodies, that are placed at such immense distances from our globe, move with an order and regularity which is not to be found in any other part of the creation. From them we have obtained all our knowledge of the seasons, and the art of reckoning by certain periods of time. Had their motions been as various and mutable as those which are observed upon the earth, we should have had no idea of the regular lapse of time or the extent of duration. This is still the state of the uncivilized and solitary barbarian, who computes his time by the falls of snow, or the progress of vegetation, and is utterly ignorant of the more refined wants of society.

The interval between the rising and setting of the sun, is a measure of time which is called a day, and is what is pointed out to us by nature herself; but as we are frequently in want of a much longer period, we are obliged to have recourse to other observations than those which depend upon the appearance and disappearance of that luminary. Some nations compute their time by the revolutions of the moon, or by months; some by the revolutions of the sun, or by years; and others again both by months and years. But this requires an exact knowledge of the celestial motions; and those who make use of both the revolutions together, should know how to conciliate, and make them agree. It was this that gave birth to the calendar; which was for a long time extremely imperfect, has been often reformed, and is still attended with many embarrassments.

Chronology is another subject so intimately connected with astronomical observations, that without their assistance, we should have been but ill acquainted with the events recorded in history, and the transactions of past ages. But it is only since certain memorable epochs, that this art can be considered as having any solid foundation. Beyond these every thing is involved in darkness and obscurity. That uncertain tradition, which, before the invention of letters, was the only vehicle of information, has confounded and disfigured every relation. We find in ancient annals but few facts that are fixed by precise dates, and even those few are seldom the same in different authors.

In this perplexed labyrinth, we have no other guide than what is afforded by the light of science. Those facts which are agreeable to the common testimony of credible historians, are considered as so many fixed points, where the weary traveller may rest himself, after his tedious researches in the barren regions of antiquity. But the observations by which the dates of early events have been determined are rare and uncommon. And what will appear still more singular is, that we owe them to the gross ignorance and superstition of the times in which they were made. The phænomena of eclipses, and particularly those of the sun, were the occasion of general consternation and terror; and from the records that have been left us of these alarming appearances, we are able to find the times in which they happened.

If the writings of an historian were entirely lost, and we could only obtain a certain vague relation of facts, without dates, but accompanied with an account of some remarkable eclipse or other celestial phænomenon; the astronomer, by his knowledge of the motion of the heavens, would be soon able to find the precise time in which they must have happened. It was in this way that the celebrated Dr. Halley determined the very day and hour of Julius Cæsar's landing in Great Britain, merely from the circumstances of his relation. And to the same cause it is owing, that the chronology of the Chinese is much more authentic than that of most other nations. Their attachment to ancient customs, and the superstition which is so intimately blended with the administration of their public affairs, has led them to preserve accounts of eclipses that prove the existence of their empire for near four thousand years past.

But an advantage still more interesting and important, is the assistance which this science affords to geography and navigation. An acquaintance with the situation and position of different countries, is not an object of mere curiosity or useless speculation; but is now become indispensably necessary, both to the gentleman and the man of business; and is generally considered as one of the most useful branches of a polite and liberal education. Politics, commerce, and philosophy, have opened a communication between almost every country on the globe. Alliances are formed between the most distant nations; traffic and science have explored every region; and the productions of different climates are transported from one extremity of the earth to the other.

When Vasco de Gama first opened the way to India by the Cape of Good Hope, and Columbus had found out a new world, the increase of riches and power resulting to certain nations from these discoveries, excited the envy and ambition of the rest, and put all Europe in motion. By a principle long established among commercial nations, the first discoverer of a new country lays claim to it as his property; and is even jealous of the road that conducted him to it. This principle, whether well or ill founded, was adopted by every power in Europe; they all became equally desirous of visiting these new climates; and the emulation for discovery continually increasing, the study of geography, and a knowledge of the globe, became a necessary pursuit.

This science, as well as that of navigation, was for a long time extremely imperfect and ill understood: the knowledge of distant countries was founded merely upon the vague and uncertain accounts of travellers, who disfigured and exaggerated all their relations by that love of the marvellous, which is so natural and congenial to the human mind: the pilot, on the other hand, confined himself to the passing of narrow seas, or coasting along the shore, and presumed not, by any dependence upon his art, to lose sight of land, and commit himself to the mercy of the winds and waves. It was astronomy that first inspired him with this confidence, and taught him to conduct his vessel, with safety, through immense oceans, which had never before been traversed by man.

In this difficult and hazardous enterprise, it is not sufficient for him to know the position of the port he designs to visit; he must also be able, at all times, to find upon what part of the globe he is; how far he has travelled; and what course he must pursue during the rest of his voyage. But these particulars can only be known from astronomical observations, and an accurate knowledge of the celestial motions. All the rules of the art are derived from this source; and though their application be attended with some difficulties, it is of the utmost importance to every mariner that they should be well understood, and properly practised; since the lives of his men, and the success of his voyage, depend upon the knowledge of them.

The government, in most countries, are so sensible of the truth of these observations, that, of late years, they have paid the utmost attention to pilotage and navigation. Since the maritime has become the preponderating force, astronomy has been considered as a science of great public utility, intimately connected with the interest of the state, and deserving the protection of every commercial nation. The great encouragement given to the professors of this science by Louis the xivth and xvth of France; the noble reward offered by the English for the discovery of the longitude at sea;

and the expensive voyages that have been undertaken for observing the transit of Venus over the sun, are all sufficient proofs of its extensive application, and practical importance.

Such are the advantages which society have derived from the cultivation of this science; but there is yet another, which, though less evident to the world in general, is nevertheless inestimable in the eyes of a philosopher. This is the knowledge which it affords us of nature; of the true system of the world; and the invariable laws by which it is governed. Astronomy has opened to us such a magnificent view of the creation, that we are struck with astonishment at the grandeur of the spectacle, and the powers of omnipotence. By looking abroad into the universe, we exalt our ideas of the supreme intelligence, and extend the narrow sphere of human conceptions; the faculties are strengthened and improved; the understanding is enlarged; and the mind, in the contemplation of so many glorious objects, finds itself drawn to that Being who informs, directs, and animates the whole.

This formal defence of a science attended with so many obvious advantages, would have been unnecessary, had I consulted only my own prepossessions in its favour; but as you are yet but little acquainted with the subject, and cannot possibly have obtained any rational conviction of its excellence, I imagined it would not be unpleasing to you, to receive some account of its practical utility and importance. To enumerate every particular of this kind, would be useless and impossible. An attentive consideration of the subject, will be more satisfactory than any previous information that can possibly be given you.

In order to form a proper judgment of any science, it is necessary to have some knowledge of its nature and design. For want of this assistance, many writers, and even some of considerable eminence in other respects, have been egregiously mistaken when they have presumed to give their opinions upon subjects which were unconnected with their own particular pursuits. Some err through ignorance, and some through prejudice. Narrow minds think nothing of importance but their own favourite studies; and whatever suits not with their humour and taste is folly and absurdity.

Actuated by a principle of this kind, the present idol of modern literature, the author of the Rambler, has been led to speak of the mathematical sciences in a manner unworthy of his abilities. "It was," he observes, "the great praise of Socrates, that he drew the wits of Greece, by his instruction and example, from the vain pursuit of natural philosophy to moral enquiries; and turned their thoughts from stars, and tides, and matter and motion, to the various modifications of virtue, and relations of life."

This thought is pursued still further, and illustrated by a story which he tells of one Gelidus, a mathematician, who was so absorbed in his speculations, that when his servant came to acquaint him a house was on fire, and the whole neighbourhood in danger of being burnt, he only replied, that it was very likely, for it was the nature of fire to act in a circle. He even divests this Pseudo-philosopher of all the common feelings of humanity, and makes him as insensible to the wants of his family, as to the distresses of his neighbours.

Such fictions are as applicable to the speculator upon morals, as to the speculator upon mathematics. There are Quixotes and pedants in every profession: but instead of attempting to ridicule a science of which he was totally ignorant, he would have done well to have learnt it himself. The mere theorist, whatever be his pursuit, is but of little use to society; but we should be careful, when we laugh at the absurdities of a visionary pretender, not to depreciate the science to which he has unhappily directed his attention. Swift ridicules mathematicians, and mathematicians enjoy the satire; not because it is founded in truth, but because it has wit and humour.

The learned Joseph Scaliger proceeded in a still more singular manner; he was a man who aimed at universal knowledge; and being particularly desirous of eminence in the sciences, he published a large volume of mathematics, in which he professed to have solved all the difficult problems, which had been considered as the master-pieces both of ancient and modern proficients: but when this work came to be examined, it was found that he was utterly unacquainted with the subjects that he had attempted to discuss. Clavius exposed his ignorance; and he, in return, not only abused

Clavius, and the rest of the mathematicians, but even reviled the science itself.

A great and comprehensive genius excludes none of the sciences; they all contribute, by various means, to adorn and embellish life; and, for that reason, ought to be cultivated and improved. Happy is the mind that is not contracted by the study of philosophy, nor enervated by the charms of the Belles Lettres; that can be strengthened by Locke; instructed by Clarke and Newton; impassioned by Cicero and Demosthenes; and elevated by the powers of Homer and Virgil.

I am, &c.

LETTER II.

OF THE FIGURE AND MOTION OF THE EARTH.

In my last letter I have shown you the excellence and advantage of astronomy in general. I shall now come to particulars; and endeavour to lead you, by gentle and easy steps, from the first principles of the science, to those parts which are the most interesting and useful. And as the earth we inhabit is constantly subject to our observation, and is that with which we are the best acquainted, a description of its form and magnitude will naturally excite your curiosity and attention.

This vast body was long considered as a large circular plane, spreading out on all sides to an infinite distance: and the heavens, above it, in which the sun, moon and stars appear to move daily from east to west, were imagined to be at no great distance from it, and to have been created solely for the use and ornament of our earth. Of this notion are the vulgar, and those who are ignorant of astronomy, to this day. But it is now well known to mathematicians and philosophers, that the earth is of a round or spherical figure, nearly resembling that of a globe.

The truth of this doctrine, without having recourse to scientific principles, will appear sufficiently evident from the voyages of those celebrated navigators Magellan, Sir Francis Drake, Lord Anson, Cook, &c. who all set out, at different times, to sail round the world; and, by steering their course continually westward, arrived, at length, at the place they departed from; which could never have happened, had the earth been of any other than a spherical or globular figure.

This form is also obvious, from the circular appearance of the sea itself, and the circumstances which attend large objects when seen at a distance on its surface. Thus, when a ship leaves the shore, we first lose sight of the hull, or body of the vessel; afterwards of the rigging; and at last discern only the top of the mast; which is evidently owing to the convexity of the water between the eye and the object; or otherwise, the largest and most conspicuous part would have been visible the longest, as is manifest from experience.

Another proof, which is of no less force than either of the former, is taken from the shadow of the earth, upon the face of the moon, in the time of a lunar eclipse. For as the moon has no light but what it receives from the sun, and the earth being, at this time, interposed between them, the moon must either wholly, or in part, become obscure. And since in every eclipse of this kind, which is not total, the dark part always appears to be bounded by a circular line, the earth itself, for that reason, must be spherical; because it is evident, that none but a spherical body can, in all situations, cast a circular shadow.

Nor are the little unevennesses on the earth's surface, arising from hills and valleys, any material objection to its being considered as a round body;

since the highest mountains we are acquainted with, bear a less proportion to the whole bulk of the earth, than the small risings on the coat of an orange bear to that fruit; or a grain of sand, to an artificial globe of a foot in diameter. And accordingly we find, that these trifling protuberances occasion no irregularities in the shadow of the earth, during the time of a lunar eclipse; but that the circumference of it always appears to be even and regular, as if cast by a body perfectly globular.

A number of other proofs might be given to the same purpose; but these are the most popular, and such as I apprehend must entirely convince every impartial enquirer, whose object is truth, and whose mind is unclouded by superstition, or an obstinate attachment to early notions and vulgar prejudices. I mention this the more particularly, because, notwithstanding the clearest arguments and most decisive demonstrations, there have been some who have violently opposed this doctrine, and even represented it as dangerous to religion and morals. Thus, several of the ancient fathers went so far out of their province, as to pronounce it heretical for any person to declare there were Antipodes, or people who live opposite to us upon the globe.

They took their objection from some passages of Scripture, which they either ill understood, or strangely perverted from their true meaning. For it is evident, that the sacred writers speak every where according to the common appearance of things; and were not so solicitous to instruct us in philosophy and astronomy, as to make us good men, by laying before us a plain rule of faith and conduct. Thus, when Joshua speaks of the sun and moon standing still while the Jews avenged themselves of their enemies; and Job describes the earth as being supported by pillars, they used the popular language of the times, without concerning themselves with the strict philosophical propriety of the terms they employed: the one being an historical relation; and the other a dramatical composition, in which such figures of speech have been always allowable.

It is not known who was the first that asserted the figure of the earth to be spherical; but the doctrine is undoubtedly very ancient. For at the taking of Babylon by Alexander the Great, eclipses were found to have been set down and computed for many centuries before that time; which, without a knowledge of the globular figure of the earth, could not have been done. Thales the Milesian, who lived about six hundred years before Christ, must likewise have been sufficiently acquainted with this subject; since, according to the testimony of Herodotus, he predicted an eclipse of the sun. "After the war, he observes, had been carried on for six years between the Medes and Lydians, as they were going out to battle, the day became presently as dark as the night; which change, though it had been predicted by Thales to the Ionians, so far terrified both parties, that they became equally desirous of a peace, which was immediately concluded." (*a*)

It appears, therefore, that, in those early times, the true figure of the earth was not unknown in the world. But it is also equally certain, that this knowledge was confined to a few; and that even some of the greatest mathematicians themselves were ignorant of it. Thus Heraclitus, a Greek philosopher, who flourished about five hundred years before Christ, supposed it to have the shape of a skiff or canoe; Anaximander, his contemporary, imagined it to be cylindrical; and Aristotle, the great oracle of antiquity, gave it a form equally remote from the truth.

These, and many other absurd opinions of the same kind, which are attributed to the ancients, plainly show the confusion and uncertainty which, at that time, attended the subject. But it is the glory of modern philosophy, that this doctrine is now set in so clear a light, and the knowledge of it so generally diffused, that it is almost impossible it should ever again be forgotten; or that the ravages of ignorant barbarians, should involve it in doubt and obscurity. We are now certain, that

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(*a*) This eclipse has given rise to many discussions, and various opinions have been advanced as to the time in which it happened; but from a paper, lately published in the Philosophical Transactions, by F. Baily, Esq., it appears to have taken place Sept. 30th, six hundred and ten years before Christ; at which time, therefore, the knowledge of astronomy must have been very considerably advanced.

the earth is not a level horizontal plane, stretched out infinitely on all sides, and with a bottomless foundation: but that it is a globular body, suspended in space, and covered on all sides with innumerable inhabitants; who, by means of the arts of navigation and commerce, can carry on a correspondence with each other, and transport their commodities to the most distant regions.

Having said thus much concerning the figure of the earth I might now proceed to give you some account of its bulk or magnitude; since this also has been ascertained; and is now settled, by mathematicians, to a sufficient degree of precision. But as the method by which the measurement of this large body was effected, as well as several other matters relating to the true figure of the earth itself, depend upon principles which will be better explained hereafter, I must defer entering into those particulars till you are further advanced in the science, and properly prepared to understand them.

That the true magnitude can be determined is not to be doubted. For the form of the earth being once known, its bulk could not long remain a secret. Accordingly we find that several of the ancient philosophers, who lived soon after the time of those before mentioned, attempted the solution of this important problem. And though the measures they have given are considerably wide of the truth, as well as different from each other, yet this was owing more to the inaccuracy of their instruments, and the want of a sufficient stock of mathematical knowledge, than to any real difficulty or impracticability in the thing itself.

But let us leave this subject for the present, and proceed to another of equal importance.—I have before proved to you, from the most indubitable arguments, that the earth is a globular body, unsupported by pillars of a bottomless foundation, as many have absurdly imagined: I shall now give you some account of its motion; a thing more remote from vulgar apprehension than the former, though equally certain and demonstrable. And, in order that you may obtain as clear and comprehensive an idea of the subject as possible, we will first take a view of the universe in general, and of that part of it in particular, which astronomers have called the visible world, or solar system.

By the universe we are to understand the whole frame of nature, as extended throughout infinite space. And, by the solar system, is meant that portion of the universe only, which comprehends the sun, planets, satellites and comets. Of which system, though contrary to what was formerly supposed, by several ancient as well as modern astronomers, the sun is now well known to be placed in the centre, and to have eleven primary planets moving round him, each in its own path or orbit.

The names of these planets, according to their distance from the centre or middle point of the sun, are, Mercury, Venus, the Earth, Mars, Vesta, Juno, Pallas, Ceres, Jupiter, Saturn, and Uranus, or the Georgium Sidus; the latter of which was discovered in the year 1781, and Vesta, Juno, Pallas, and Ceres, since the commencement of the present century; among which it is to be observed, that the two first, Mercury and Venus, having their orbits within that of the Earth, are called inferior planets, and the others, which revolve beyond it, are called superior planets.

Now if we can form a notion of the manner in which our earth moves, we shall easily conceive the motions of all the rest of the planets, and by that means obtain a complete idea of the order and œconomy of the whole system. For which purpose, nothing more is necessary than to consider the common appearances of the heavens, which are constantly presented to our view, and attend to the consequences that follow from such observations. For since it is well known that the sun and stars appear to move daily from east to west, and to return nearly to the same places in the heavens again in twenty-four hours, it follows that they must really move, as they appear to do, or else that we ourselves must be moved, and attribute our motion to them; it being a self-evident principle, that, if two things change their situation with respect to each other, one of them, at least, must be moved.

But if this change be owing to the revolution of the stars, we must suppose them to be endowed with a motion so amazingly rapid as to exceed all conception. Since it is known, by calculations founded on the surest observations, that their distances from us are so immense, and the orbits in which they revolve so prodigiously great, that the nearest of them would move at least a hundred thousand miles in a minute. Now as nature never does that in a complicated and laborious manner which may be done in a more simple and easy one; it is certainly more agreeable to reason, as well as to the power and wisdom of the Creator, that these effects should be produced by the motion of the earth; especially as such a motion will best account for all the celestial appearances, and, at the same time, preserve that beautiful simplicity and harmony, which is found to prevail in every other part of the creation.

This argument will also appear still more forcible, if we compare the vast bulk of the celestial bodies with the bulk of our earth. For it is well known to astronomers, that the sun is above a million of times bigger than the earth; and, consequently, judging from analogy, it follows that many of the stars are at least of an equal magnitude. It is much more probable, therefore, that the earth revolves round its axis, with an easy natural motion, once in twenty-four hours, than that those vast bodies should be carried from one place to another, with such incredible velocities.

Nor is it any objection to this rotation of the earth, that we are unable to perceive it. For as the motion of a ship at sea, when she sails swiftly over the smooth surface of the water, is almost, if not wholly imperceptible to the passengers and company on board; much more so must it be with such a large body as the earth, that has no impediments or obstacles of any kind in its way, to disturb its motion. A balloon, turning upon its axis, as it floats through the atmosphere, affords a sensible representation of the earth, in its annual progress round the sun:

> "That spinning sleeps,
> On her soft axle, as she paces even,
> And bears us swift with the smooth air along."
>
> MILTON.

And, in a manner equally easy, may another objection be removed, which has frequently been brought against this doctrine. It has been asserted, that if the earth moved, a stone dropped from the top of a tower, or any other high building, would not fall just at the bottom of it, as the building must have advanced considerably forward during the time of the fall. But this is evidently a mistake; for it is well known, by repeated experiments, that if a body be projected from another body in motion, it will always partake of the motion of that other body. Thus, a stone dropped from the top of a mast, whilst the ship is under sail, is not left by the vessel, but will fall at the foot of the mast. And if a bottle of water be hung up in the cabin, with its neck downwards, it will empty itself, drop by drop, into another bottle placed exactly beneath it, though the ship shall have run many feet whilst each drop was in the air. (*b*)

(*b*) The objection above mentioned, was one of the principal arguments, of a philosophical nature, that was advanced against the rotation of the earth, by the opposers of the new system; and it was thought, for some time, to be unanswerable. But when the composition and resolution of forces

This motion of the earth round its axis, which, from the instances already given, has been rendered sufficiently evident, is called its diurnal, or daily motion; and is that which occasions the regular return of day and night, and all the celestial appearances before mentioned. But there is also another motion of the earth, called its annual, or yearly motion, which occasions the various vicissitudes of the seasons, summer, winter, spring, and autumn.

And the proofs of this second motion may be easily gathered from celestial appearances, in nearly the same manner as the former. For as the sun seems to move round the earth, from east to west, in the space of a day, which is really owing to the diurnal rotation of the earth upon its axis, in a contrary direction, so, likewise, he seems to have an annual motion in the heavens, and to rise and set continually in different parts of them; which is certainly occasioned by the daily motion of the earth in its orbit, or path round that luminary, which it completes in the space of a year.

That the earth, indeed, is not the centre of the

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became better understood, it was perceived, that a body dropped from the top of a tower, instead of being left behind, or falling to the westward of it, ought to be carried forward, and fall to the eastward, in consequence of the centrifugal force being something greater at the top of the tower than at the bottom; and from several accurate experiments this has been found to be the case. Thus a circumstance which was brought forward to refute this doctrine, might now, if necessary, be advanced as a demonstration in support of it.

celestial motions, may be easily shown from the revolutions and appearances of the different planets which belong to our system. For it is certain, that wherever the sun may be placed, the orbit of Venus surrounds and incloses him within itself; and therefore Venus, whilst she describes this orbit, must really move round the sun. For this planet is observed to be sometimes above, or beyond the sun; and sometimes below him, or between the sun and us: but she was never known to come in opposition to the sun, or to be seen in the east when he was in the west; which must necessarily have happened, if she had performed her revolution round the earth, in an orbit like that of the moon.

In like manner, Mercury is always found to keep in the neighbourhood of the sun, without ever receding from him so far as Venus; but as he is continually involved in the splendor of the sun's rays, he can seldom be seen without the assistance of a telescope. The superior brightness of this planet affords, likewise, a sufficient proof, that he must be much nearer to the sun than any of the rest; from both of which circumstances it is evident, that the orbit of Mercury is included within the orbit of Venus, and that, like that planet, he regards the sun as the centre of his motion.

Mars, Vesta, Juno, Pallas, Ceres, Jupiter, Saturn, and the Georgium Sidus, being superior planets, must necessarily include the earth in their orbits; but from their various elongations, or distances from the sun at different times, as well as from their stationary and retrograde appearances, it is plain that the sun, and not the earth, must also be the centre of their motions, or the body round which they perform their respective revolutions.

Hence it appears, that the earth itself must likewise move round the sun. For since, by the place it obtains in the system, it has those moveable bodies Mercury and Venus on one side, nearer to the sun, and Mars, and the other superior planets on the other side, more remote, it follows, from analogy, that, being of the same nature as they are, it must also partake of the same sort of motions. And as the earth is placed between Venus and Mars, so the period likewise in which it performs its course round the sun, is a mean between the periods of those planets, being greater than the one, and less than the other, as would naturally follow from such a motion.

The absurdity, indeed, of supposing the earth a sedentary and immoveable body, is sufficiently exposed in the following speech of Adam to the angel Raphael, when he is enquiring concerning the nature of the celestial motions:

"When I behold this goodly frame, this world
Of heav'n and earth consisting, and compute
Their magnitudes, this earth, a spot, a grain,
An atom, with the firmament compared
And all her number'd stars, that seem to roll
Spaces incomprehensible (for such
Their distance argues, and their swift return
Diurnal) merely to officiate light
Round this opacous earth, this punctual spot,
One day and night; in all their vast survey

Useless besides; reasoning I oft admire
How Nature, wise and frugal, could commit
Such disproportions."——

MILTON.

Many other proofs might also be given, which establish this doctrine upon the surest foundation, and secure the abettors of it from all possibility of contradiction. But in a thing which admits of absolute certainty, there have been those who were so perversely ignorant as to refuse all conviction. This opinion of the motion of the earth, like that of its figure, has met with continual opposition; and its advocates have been branded with the most ignominious titles, and persecuted with all the rage of fanaticism.

The celebrated Aristarchus of Samos, for defending this doctrine, was brought before the bench of the Areopagites, and accused, by his adversary, of having violated the laws of religion and morality. And, little more than two hundred years since, the great Galileo met with the same fate. He was summoned before the tribunal of the inquisition, and obliged solemnly to abjure his astronomical tenets; that the sun was immoveable, in the midst of the universe, and that the earth revolved round it as its proper centre. With which requisition he was forced to comply; and to declare that he did with a sincere heart, and faith unfeigned, abjure, curse and detest, these errors and heresies.

Such are the obstructions that have been constantly thrown in the way of science and knowledge. But, happily for mankind, the persecuting spirit of bigotry and enthusiasm is now losing ground; and the dogmas of papal authority, are as little regarded as the infallibility of its decisions. Philosophers, of every country, embrace the doctrine of Galileo, and are no longer subject to the arbitrary control of monks and inquisitors. That furious spirit of despotism and intolerance which has long held an usurped dominion over the powers of the mind, as well as those of the body, is at length giving way to a more refined polity; and the friends of mankind have reason to hope, that the time is not far off, when the greater part of Europe will be suffered to enjoy, in quiet, that freedom of opinion, both in religion and the sciences, which is the birthright privilege of every human being.

LETTER III.

OF THE SOLAR SYSTEM, AND THE FIRMAMENT OF THE FIXED STARS.

As the figure and motion of the earth are now sufficiently established, it will be proper to turn our attention to the rest of the planets; and, from describing their nature and properties, to exhibit a summary view of the whole system. In the first place, then, it is to be observed, that the planets are all opaque spherical bodies, like our earth, that have no proper light of their own, but shine by means of the borrowed light which they receive from the sun: and therefore, only that side of them which is turned towards him, can receive the benefit of his light, whilst the opposite side, which the borrowed rays cannot reach, remains in obscurity, till by the rotation of the planet on its axis, it is itself turned towards the sun, and becomes equally illuminated by his beams.

The planets are also not only similar to our earth in form and structure, but they are likewise known to perform their revolutions round the sun in the same manner. For by the regular appearance and disappearance of several remarkable dark spots, which, by means of a telescope, are constantly to be seen on their bodies, we are able to ascertain that they must have such a motion about their axes, as answers to the diurnal rotation of the earth. And from their seeming at certain times to be moving forward, and at others to be stationary, and then to go backwards, or be retrograde, we are equally certain, that they must have such a progressive motion round the sun, as answers to the annual revolution of the earth in its orbit.

Mercury, the nearest planet to the sun, goes round him in about eighty-seven days and twenty-three hours, or a little less than three months; which is the length of his year. But being seldom seen, on account of his proximity to the sun, and no spots appearing on his surface, or disk, the time of his rotation upon his axis, or the length of his days and nights, is not so accurately determined as in some of the other planets; though Schroeter, a German astronomer, has lately found, from the variation of the horns of his phases, that he has such a motion; which, according to his estimation, is performed in little more than twenty-four hours, being nearly the same as that of the earth. His distance from the sun is computed to be about thirty-six millions of miles, and his diameter three thousand one hundred and twenty; and in his course round the sun, he moves at the rate of a hundred and five thousand miles an hour.

This planet, when viewed, in different positions, with a good telescope, seems to have all the phases or appearances of the moon, except that he can, at no time, be seen entirely round, or quite full; because his enlightened side is never turned directly towards us, except when he is so near the sun as to be hid in the splendour of his beams. Hence, from these phases, it is evident, that he shines not by any light of his own, as the sun does, as he would in that case certainly appear, at all times, round like that luminary.

Venus, the next planet above Mercury, is computed to be sixty-eight millions of miles from the sun, and by moving at the rate of seventy-six thousand miles an hour, she completes her annual revolution in 224 days and 16 hours, or about seven months and a half. Her diameter is seven thousand seven hundred miles, and her diurnal rotation on her axis, is performed in 23 hours and 21 minutes. When this planet appears to the west of the sun, she rises before him in the morning, and is called the Morning Star; and when she appears to the east of the sun, she shines in the evening after he sets, and is then called the Evening Star; being in each situation, alternately, for about 290 days: and during the whole of her revolution, she appears, through a telescope, to have all the shapes and appearances of the moon.

The next planet above Venus, in our system, is the Earth. Its distance from the sun is ninety-three millions of miles, and by moving at the rate of fifty-eight thousand miles an hour, its annual revolution is performed in 365 days, 6 hours, or the space of a year; which motion, though 120 times swifter than that of a cannon-ball, is but little more than half the velocity of Mercury in his orbit. The earth's diameter is about seven thousand nine hundred miles; and as it turns round its axis every 24 hours, from west to east, it occasions an apparent motion of all the heavenly bodies, from east to west, in the same time.

Next above the Earth's orbit, is Mars, whose distance from the sun is computed to be about one hundred and forty-two millions of miles. He moves at the rate of fifty-five thousand miles an hour, and completes his revolution round the sun in a little less than two of our years. His diameter is four thousand three hundred and ninety miles; and his diurnal rotation upon his axis is performed in about 24 hours and 39 minutes. This planet sometimes appears gibbous, but never horned, like the moon, which plainly shows, that his orbit includes that of the earth, and that he shines not by his own native light.

The next planet in our system is Vesta, for the knowledge of which we are indebted to Dr. Olbers of Bremen, being first discovered by him March 29th, 1807. Its distance from the sun is about two hundred and twenty-three millions of miles, and its annual revolution in its orbit is performed in about 3 years $7\frac{1}{4}$ months. But neither its diameter, nor the duration of its diurnal rotation, have yet been ascertained.

Juno, the next in order, is another new planet, discovered by Mr. Harding, at the observatory at Lilienthal, near Bremen, Sept. 1st, 1804. The mean distance of this planet from the sun is estimated at two hundred and fifty-three millions of miles, and its annual revolution is performed in 4 years, 4 months, and 6 days; but its diameter, and the time of its revolving on its axis is unknown.

The next superior planet above Juno, is Pallas, which was first observed by Dr. Olbers, March

28th, 1802: the mean distance of which, from the sun, is reckoned to be about two hundred and sixty-three millions of miles, and its revolution in its orbit is made in about 4 years 7 months and 10 days; but like the two former, its diameter and diurnal rotation have not been at present ascertained.

Ceres is the next higher planet, in our system; which was first discovered by Piazzi, of Palermo, Jan. 1st, 1801. Its mean distance is nearly the same as that of Pallas, being estimated, in round numbers, at two hundred and sixty-three millions of miles; and consequently its annual revolution is also nearly the same, being performed in 4 years, 7 months, and 11 days.

The extreme minuteness of these planets, as well as the little time since they have been discovered, and their great distance from us, render the results of our observations upon them in some measure uncertain; we have, however, reason to conclude, that none of their diameters exceed four hundred miles, nor are less than a hundred miles. But, at present, no accurate estimate can be made of the time of their diurnal rotation.

Jupiter, is the largest of all the planets, and is reckoned to be about four hundred and eighty-five millions of miles from the sun; and by going at the rate of twenty-nine thousand miles an hour, he completes his annual revolution in something less than twelve of our years. His diameter is computed to be ninety-one thousand five hundred miles; and, by a prodigiously rapid motion upon his axis, he performs his diurnal rotation in 9 hours and 55 minutes.

Saturn, the next planet in the system above Jupiter, is about eight hundred and ninety millions of miles from the sun; and by moving at the rate of twenty-two thousand miles an hour, he performs his annual circuit round that luminary in a little less than 29½ of our years. His diameter is computed to be about seventy-six thousand miles; but, on account of his immense distance, and the deficiency of light occasioned by such a remote situation, the time of his diurnal rotation upon his axis was formerly unknown. It is now however ascertained to be about 10 hours 16 minutes.

The next and highest planet in our system at present known, is Uranus, or the Georgium Sidus; which was first discovered by Dr. Herschel, March 13th, 1781. The elements of this planet have been now accurately determined; from which it appears, that its mean distance from the sun is about one thousand eight hundred millions of miles, and its diameter thirty-five thousand. Its annual revolution is performed in about 84 years; but the time of its revolving on its axis has not been discovered by observation; although, from analogy, Laplace conceives that it must be performed in about the same time, or rather less, than that of Saturn.

The various particulars of this and the other new planets, being highly interesting, I shall speak of them more at large in some future letter. At present it is only necessary to observe, that beside the primary planets here mentioned, there are eighteen others, called secondary planets, or satellites, which regard the primaries as the centres of their motions, and revolve about them in the same manner, as those primaries themselves revolve about the sun.

One of the most conspicuous of these satellites is the Moon, who is a constant attendant on our Earth; and, whilst she accompanies it in its annual progress through the heavens, keeps revolving round it continually, by a different motion, in the space of a month. The Moon's diameter is about two thousand one hundred and sixty miles; her distance from the Earth two hundred and thirty seven thousand miles; and in bulk she is about one sixteenth part of that of the Earth. Jupiter has four such moons, Saturn seven, and Uranus six; and from the continual change of their phases, or appearances, it is evident that these also are opaque bodies, like the planets, and shine only by means of the borrowed light which they receive from the sun.

It may also be observed, that our Earth is a moon to the Moon, waxing and waning in exactly the same manner; but appearing always stationary, and presenting a diameter near four times greater than hers appears to us; the whole disc being thirteen times larger, and, of course, affording a proportional quantity of light. When she changes to us, the Earth will appear full to her, and when she is in her first quarter to us, the Earth will be in its third quarter to her. And, as her axis is almost perpendicular to the plane of the ecliptic, one half of her orb will be constantly illuminated by the reflected light afforded by the Earth in the sun's absence, whilst the other half will have a fortnight's darkness, and a fortnight's light, alternately.

The rotation of the Moon upon her axis, is also performed in exactly the same time that she goes once round the Earth, as is evident from her always presenting the same face to us during the whole of her monthly revolution; and, on this account, it is plain that the inhabitants of one half of the lunar world, are totally deprived of a sight of the Earth, and must for ever remain ignorant of its existence, unless business, or pleasure, leads them to explore the opposite hemisphere; where they may have a full view of our globe, appearing to them like a newly-created planet, with a disc near 13 times larger than that of the sun.

A number of other circumstances relating to this subject, will be mentioned in their proper places. But a general idea of the solar system, together with the periods, distances, bulks, &c. of the planets, will be best acquired from the following table, which is formed from the latest observations of the best modern astronomers. A minute exactness in these matters, cannot be easily obtained; and as the nearest approximate numbers are better retained in the memory than those which are more accurate, I have preferred this method of express-ing them for the present, but, when occasion requires, shall be more precise. (c)

Mean and proportional Distances of the Planets from the Sun.

	English miles.	Prop. dist.
Mercury	36 millions	0·4
Venus	68	0·7
Earth	93	1·0
Mars	142	1·5
Vesta	223	2·3
Juno	253	2·6
Pallas	263	2·7
Ceres	263	2·7
Jupiter	485	5·2
Saturn	890	9·5
Uranus	1800	19·1

Moon's distance from the Earth 237000 miles.

Times of Periodic Revolutions of the Planets.

	Days.
Mercury	87·97
Venus	224·70
Earth	365·25
Mars	686·98
Vesta	1313·00
Juno	1586·00
Pallas	1680·00
Ceres	1680·00
Jupiter	4332·60
Saturn	10759·00
Uranus	30688·90

The Moon revolves about the Earth in 27 days 7·716 hours.

(c) The explanation of the terms made use of in this Table, as well as in several other parts of the book, are to be found at the end of the work.

Diameters of the Sun and Planets.

	Real diam. Eng. miles.	App. diam.
Sun	883246	32′ 3″
Mercury	3123	0 7
Venus	7702	0 17
Earth	7916	. .
Mars	4398	0′ 11″
Vesta, Juno, Pallas, Ceres	Not known, but probably none less than 100 miles, nor greater than 400 miles.	
Jupiter	91522	0 39
Saturn	76018	0 18
Uranus	35100	0 4
The Moon	2160	31 8

Proportion of Bulk, and Densities, of the Sun and Planets.

	Prop. bulk.	Prop. dens.
Sun	1380000	$\frac{1}{4}$
Mercury	$\frac{1}{15}$	2
Venus	$\frac{8}{9}$	$1\frac{1}{4}$
Earth	1	1
Mars	$\frac{7}{24}$	$\frac{7}{10}$
Jupiter	1400	$\frac{23}{100}$
Saturn	1000	$\frac{9}{100}$
Uranus	90	$\frac{1}{5}$
Moon	$\frac{1}{16}$	$\frac{1}{60}$

The bulks and densities of Vesta, Juno, Pallas, and Ceres, are not known.

Diurnal Rotation of the Sun and Planets.

Sun	25 days	12 hours
Mercury		24·0038
Venus		23·3666

Earth	23·9333
Mars	24·6561
Jupiter	9·9360
Saturn	10·2720
The Moon	27 days 7·716 hours.

Note. The times of rotation of the five new planets have not at present been ascertained.

Eccentricities of the Planetary Orbits, in parts of the semi-transverse axis.

Mercury	0·205
Venus	0·007
Earth	0·017
Mars	0·093
Vesta	0·097
Juno	0·254
Pallas	0·246
Ceres	0·076
Jupiter	0·048
Saturn	0·056
Uranus	0·047

Inclination of the Planetary Orbits.

Mercury	7°	40′
Venus	3	23
Earth	0	00
Mars	1	51
Vesta	7	5
Juno	13	4
Pallas	34	38
Ceres	10	38
Jupiter	1	19
Saturn	2	29
Uranus	0	46

Besides their satellites, or moons, the two planets, Jupiter and Saturn, are distinguished from the rest in a manner still more remarkable. The body of Jupiter is surrounded by several parallel faint and variable substances called Belts. And Saturn has a magnificent double luminous Ring, which encompasses him, at such a distance, that stars have sometimes been seen between the inward surface of the ring and the body of the planet. But neither these appearances, nor the satellites themselves, can be discerned without the assistance of a telescope.

Various instruments have been constructed by ingenious mechanics, for the purpose of exhibiting, in a sensible manner, the several motions of these bodies; but many of them are so complicated in their construction and appearance, that they rather confuse the student, and render the subject, which they are intended to illustrate, more obscure and complicated. There are others, however, of a more simple nature, which may, in some cases, be used to advantage; of which kind is the planetarum, represented in Plate II.; which by means of its internal mechanism, gives motion to the six primary planets, Mercury, Venus, the Earth, Mars, Jupiter and Saturn; the satellites and other planets being omitted to prevent confusion. (*d*)

Archimedes is said to have invented an instru-

(*d*) These are proportioned, as near as can be done on a small scale, to the various magnitudes, distances and periodic revolutions of the planets they are meant to represent; and when put in motion give a tolerable idea of the mechanism of the solar system; or, at least of that part of it which is comprehended by them.

ment of this kind, which exhibited all the celestial motions in the most natural order; but of the exact nature of its construction we are not informed. It is frequently alluded to by the Latin poets, particularly by Claudian, whose much admired epigram on this subject is in English, as follows:

> "When in a glass's narrow sphere confined,
> Jove saw the fabric of th' Almighty mind,
> He smiled and said; "Can mortal's art alone
> Our heavenly labours mimic with their own?
> The Syracusan's brittle work contains
> Th' eternal laws that through all nature reigns:
> Framed by his art see stars unnumbered burn,
> And in their courses rolling orbs return;
> His sun through various signs describes the year,
> And every month his mimic moons appear.
> Our rival's laws his little planets bind,
> And rule their motions with a human mind.
> Salmoneus could our thunder imitate;
> But Archimedes can a world create."

Having thus enumerated the planets and their attendants; the comets are now the only bodies belonging to our system, which remain to be mentioned; and of these the number is unknown. But from a variety of observations which have been made on some of the most remarkable ones, it has been found that they move round the Sun, and cross the orbits of the planets in various directions. They are also solid opaque bodies, of different magnitudes, like the planets; and are distinguished from them principally, by long fiery tails, which continually issue from that side of them which is furthest from the sun.

The orbits in which these vast bodies move, are exceeding long ovals, or very eccentric ellipses, of such amazing circumferences, that in some parts of their journey through the heavens, they approach so near the sun, as to be almost vitrified by his heat; and then go off again into the regions of infinite space, to such immense distances, as must nearly deprive them of the light and heat which the rest of the planets receive from that luminary.

What a magnificent idea of the Creator and his works is here presented to the imagination! The sun, a stupendous luminous body, is placed in the centre of the system, round whose orb, the planets, satellites, and comets, perform their revolutions, with an order and regularity that must fill our minds with the most exalted conceptions of their divine Original. Who can contemplate the magnitudes and distances of these vast bodies, and the beautiful harmony of their motions, and not be struck with the grandeur of the scene, and the power of omnipotence! But what must be our astonishment when we are told, that this glorious system, with all its superb furniture, is only a small part of the universe; and if it could be wholly annihilated, would be no more missed, by an eye that could take in the whole creation, than a grain of sand from the sea-shore.

To form a proper idea of the extent of the universe, and the more glorious works of creation, we must turn our attention to the starry firmament; and visit those numerous and splendid orbs which are every where dispersed through the heavens, far beyond the limits of our planetary system.

" We, though from heav'n remote, to heav'n will move
With strength of mind, and tread the abyss above;
And penetrate, with an interior light,
Those upper depths, which nature hid from sight.
Pleased we will be to walk along the sphere
Of shining stars, and travel with the year;
To leave the heavy earth, and scale the height
Of Atlas, who supports the heav'nly weight;
To look from upper light, and thence survey
Mistaken mortals wand'ring from the way."

OVID.

It is in these higher regions, that the Almighty has displayed himself in such indelible characters as must rouse the most insensible spectator, and fill his mind with admiration and astonishment. By contemplating the magnitudes and distances of the fixed stars, all partial considerations of high and low, great and small, vanish from the mind; and we are presented with such an unbounded view of nature, and the immensity of the works of creation, as overpowers all our faculties, and makes us ready to exclaim with the Psalmist, "Lord, what is man, that thou art mindful of him, or the son of man, that thou regardest him?"

The fixed stars are distinguished from the planets by being more bright and luminous, and by continually exhibiting that appearance which we call the scintillation, or twinkling of the stars. This, probably, arises from their appearing so extremely small, that the interposition of any very minute substance, of which there are many constantly floating in the atmosphere, deprives us of the sight of them: but as the interposed body soon changes its place, we again see the star; and this succession being perpetual, occasions the twinkling.

But a more remarkable property of the fixed stars, and that from which they obtained their name, is their never changing their situation with regard to each other, as the planets do. For though the revolution of the earth upon its axis occasions an apparent daily motion of the whole frame of the heavens, in a contrary direction; yet any two fixed stars being observed, at several distant intervals of time, will always be found to preserve the same relative position during the whole of this revolution.

It is not to be imagined, that the stars are placed in one concave surface, so as to be all equally distant from us; but that they are dispersed through unlimited space, in such a manner, that there may be as great a distance between any two neighbouring stars, as there is between our sun and those which are the nearest to him. So that an observer, who could be placed near any fixed star, would consider it alone as a real sun, and the rest only as so many shining points, placed at equal distances from him in the firmament.

It is generally supposed, that the difference we perceive in the size of the stars, arises from their different distances, and that those which appear the largest are the nearest to us; hence these are said to be of the first magnitude; those that appear something less, of the second magnitude; and so on as far as the sixth; which includes all the stars that are visible without a telescope. And though in a clear winter's night, when the moon is below the horizon, the stars seem to be innumerable, yet when the whole firmament is divided into signs and constellations, as it has been by the ancients, the number which can be seen at once, by the naked eye, does not far exceed a thousand.

Since the invention of the telescope, indeed, the number of the fixed stars has been justly considered as immense; because the more perfect our instruments are, the more stars always appear to us; and as we cannot conceive any bounds to infinite space, no more can we even in imagination affix any limit to the number of the stars, which are dispersed through it in every direction. The Galaxy, or Milky-Way, is one continued cluster of small stars, which combine to illuminate that part of the firmament, and diffuse such a shining whiteness through it; and in this portion of the heavens only, the telescope discovers to us that their number is without bounds.

"A broad and ample road, whose dust is gold,
And pavement stars, as stars to thee appear,
Seen in the Galaxy, that milky way,
Which nightly, as a cirling zone thou seest
Powder'd with stars."———

MILTON.

The immense distance of the fixed stars from our earth, and from each other, is, of all considerations the most proper for raising our ideas of the works of God, and the extent of the creation. The largest star in appearance, and therefore probably the nearest to us, is Sirius, or the dog-star. Now the earth, in moving round the sun, is one hundred and eighty-six millions of miles nearer to this star in one part of its orbit, than in the opposite one; and yet its magnitude does not appear to be in the least altered, or its distance affected by it. The celebrated Huygens carried his thoughts so far upon this subject, as to believe that there might be stars, at such inconceivable distances from our earth, that their light, though it is known to travel at the rate of more than ten millions of miles in a minute, has not yet reached us since the creation of the world.

The stars being at such prodigious distances from the sun, cannot possibly receive from him so strong a light as they seem to possess, nor even a degree of brightness sufficient to make them visible to us. For his rays would be so scattered and dissipated before they could reach such remote objects, that they could never be transmitted back to our eyes, so as to render those objects visible by reflection. The stars, therefore, shine with their own native and unborrowed lustre, and are totally different from the planets, which are opaque or dark bodies, without any other light than what they receive from the sun.

Modern discoveries, also, make it probable, that each of these fixed stars is a sun, having worlds rovolving round it, as our sun has the earth and other planets revolving about him. For it is not to be imagined that the Almighty, who always acts with infinite wisdom, and does nothing in vain, should have created so many glorious suns, fit for so many important purposes, and placed them at such distances from one another, without proper objects near enough to be benefited by their influence. Whoever supposes that they were made only to give a faint glimmering light to the inhabitants of this globe, must have a very superficial knowledge of astronomy, and a mean opinion of the divine wisdom: since many of the stars are so far from benefiting us, that they cannot be seen without the assistance of a telescope; and the Deity, by an infinitely less exertion of creating power, could have given our earth much more light, by means of one single additional moon.

Instead, therefore, of one sun, and one world only in the universe, as the unskilful in astronomy imagine, that science discovers to us such an inconceivable number of suns, systems, and worlds, dispersed through infinite space, that our planetary system compared with the whole, appears but as a point, or atom, and is almost lost in the immensity of creation. The Georgium Sidus, notwithstanding, revolves round the sun in an orbit of above ten thousand millions of miles in circumference, and some of the comets make excursions of many millions of miles beyond this; and yet, at that amazing distance, they are incomparably nearer to the sun than to any of the fixed stars; as is evident from their keeping clear of the stars, and returning periodically by virtue of the sun's attraction.

Since the fixed stars, therefore, are prodigious spheres, possessing in themselves the power of illumination, and are at inconceivable distances from each other, as well as from us, it is reasonable to conclude that they are made for the same or similar purposes with our sun; to bestow light, heat, and vegetation on a certain number of planets and satellites which revolve about them. And, from what we know of our own system, it seems probable, that all the rest are with equal wisdom contrived, situated, and provided with accommodations for rational inhabitants. For although there is an infinite variety in those parts of the creation, which we have an opportunity of examining, yet there is a general analogy running through and connecting all the parts into one scheme, one design, one whole!

To conclude, in the words of an admired writer upon this subject; "What an august, what an amazing conception, if human imagination can conceive it, does this give of the works of the Creator! Thousands of thousands of suns, multiplied without end, and ranged all around us, at immense distances from each other, attended by ten thousand times ten thousand worlds, all in rapid motion, yet calm, regular, and harmonious, invariably keeping the paths prescribed them; and these worlds peopled with myriads of intelligent beings, formed for an endless progression in perfection and felicity.

"If so much power, goodness and magnificence, be displayed in the material creation, which is the least considerable part of the universe, how great, wise and good must HE be, who made and governs the whole!"

LETTER IV.

OF THE SYSTEMS OF PTOLEMY, TYCHO BRAHE, AND COPERNICUS.

Of all the gifts and benefits which the Author of nature has so plentifully bestowed upon mankind, those which consist in the improvement of the mind by arts and sciences are the most estimable. And, independently of the practical advantages which society derives from the cultivation of them, they afford us more pure and unalloyed pleasures than any of the gratifications of sense can possibly bestow.

The unbounded view of nature, which I have laid open in my last letter, and the wonderful operations of the Deity in every part of this stupendous fabric, will not only ennoble the mind and strengthen the understanding, but it is likewise calculated to answer a still more important purpose, that of laying a sure foundation for natural religion, and leading us, in the most satisfactory manner, to a knowledge of the great Author and Governor of the universe.

To study nature, is to search into the works of the creation; where every step must lead us to form more exalted ideas of the Divine Being who prevails throughout, directs and animates the whole. From the microscopic animalcule, which is indiscernible to the unassisted eye, to the great and immeasurable luminaries of heaven, he is every where present. And whilst we perceive his wisdom and power thus equally displayed in the motions and operations of the greatest and subtilest parts of the creation, we cannot but be excited and animated to correspond with the general harmony.

What sublime ideas of this great Being, do we obtain from contemplating the vast diversity of his works, which the cursory survey we have taken of them, imperfect as it is, affords us; and how is the mind enlarged and captivated by the astonishing scenes, and agreeable reflections, which these enquiries continually present to our view. That part of nature, which is the immediate object of the senses is very imperfect, and but of small extent; but by the assistance of art, and the help of our reason, it is enlarged till it loses itself in an infinity on either hand. The immensity of things on one side, and their minuteness on the other, carry them equally out of our reach, and conceal from us the greater and more noble part of physical operations. As magnitude of every sort, abstractedly considered, is capable of being increased to infinity, and is also divisible without end; so we find that, in nature, the limits of the greatest and least dimensions of things are placed at an immense distance from each other. We can perceive no bounds to the vast expanse in which natural causes operate, and are no less at a loss when we endeavour to trace things to their elements, and to discover the limits which conclude the subdivisions of matter.

The objects which we commonly call great vanish, when we contemplate the vast body of the earth; the terraqueous globe itself is soon lost in the solar system; in some parts it is seen only as a distant star; and in others it is unknown, or visible only at certain times, by vigilant observers, assisted, perhaps, by instruments like our telescopes. The sun himself dwindles into a star; Saturn's vast orbit, and the orbits of all the comets, crowd into a point, when viewed from numberless places between the earth and the nearest fixed stars: other suns give light to illuminate other systems, where our sun's rays are unperceived; but these also are swallowed up in the immeasurable expanse. Even all the systems of the stars, which sparkle in the clearest sky, must possess but a small part of that space over which such systems are dispersed; since more stars are discovered in one constellation, by the telescope, than the naked eye perceives in the whole heavens.

And after we have risen thus high, and left all definite measures so far behind us, we find ourselves no nearer to a term or limit; for all this is nothing to what may be displayed in the infinite expanse, beyond the remotest stars that have ever been discovered.

In like manner, if we descend in the scale of nature, towards the other limit, we find a like gradation from minute objects to others inconceivably more subtile; and are led as far below sensible measures, as we were before carried above them, by similar steps, which soon become lost in equal obscurity. From microscopic observations that discover animals, thousands of which would scarcely form a particle discernible to the naked eye; from the propagation, nourishment and growth of those animals; from the subtilty of the effluvia of bodies, which retain their particular properties after the utmost degree of rarefaction; from many astonishing experiments of the chemists; and especially from the inconceivable minuteness of the particles of light, which find a passage through the pores of transparent bodies in all directions, it appears, that the sub-divisions of the parts of bodies descend by a number of steps or gradations that surpasses all imagination, and that nature is inexhaustible on every side, the two extremes of great and small being equally removed from our comprehension.

Nor is it in the magnitude of bodies only that this endless gradation is to be observed. Of motions, some are performed in moments of time, and others are finished in very long periods; some are too slow, and others too swift to be perceived by us. So that wherever we turn ourselves, we are lost in an endless labyrinth; and find fresh reasons, at every step, to adore and venerate that Being, whose works are so various and hard to be comprehended.

But it is now time to leave these pleasing digressions, and to give you some account of the different opinions of philosophers, concerning the situation of the heavenly bodies, or the place which they possess in the universe; in which enquiry you will not be surprized to find, that they are no less various and contradictory, than those relating to the figure and motion of the earth, as mentioned in a former letter. For mankind must have made considerable advances in astronomy, before they could so far disengage themselves from the prejudices of sense and popular opinion, as to believe in a doctrine so sublime and remote from vulgar apprehension, as that which the moderns have now firmly established.

The beginnings of sciences, as well as of other things, are uncertain and obscured with fables; we collect, however, from several testimonies, that the true doctrine of the planetary motions was known in the world from the most early ages, and taught by some of the greatest and wisest men of antiquity. That admirable philosopher Pythagoras, who flourished near five hundred years before Christ, was undoubtedly acquainted with this doctrine. But, from the accounts of his disciples and followers, it is evident, that it was not the result of his own observations; but that he had received hints of it from some more enlightened nations, who had made greater advances in the science.

It is most probable, indeed, that the doctrine was transplanted by him from the east, in which part of the world he spent two and twenty years, and scrupled not to comply with all the customs peculiar to the eastern nations, in order to obtain free access to their priests and magi, to whom almost all knowledge of arts and sciences was then confined. And as he was a man of extraordinary qualities, and had an insatiable thirst for knowledge, so he seems to have been the most successful of any of the ancients in making himself acquainted with their philosophy.

We accordingly find, that many of his followers had just notions of the planetary system; and not only taught that the earth moved daily on its own axis, and revolved annually round the sun, but gave such an account of the comets as is agreeable to modern discoveries. They also taught that every star was a world, having each of them something corresponding to our earth, such as air and water; and that the moon, in particular, was inhabited by larger and more beautiful animals than those of our globe. This system, however, was so extremely opposite to the prejudices of sense and opinion, that it never made any great progress in the ancient world. The philosophers of antiquity, despairing of being able to overcome ignorance by reason, set themselves to adapt the one to the other, and to form a reconciliation between them.

The most celebrated of those who undertook to establish an hypothesis of this kind, and to defend it with a show of reason and argument, was Ptolemy, an Egyptian philosopher, who lived in the time of the emperor Adrian, about an hundred and thirty years after Christ. He supposed with the vulgar, who measure every thing by their own conceptions, that the earth was fixed immoveably in the centre of the universe; and that the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn, revolve round it in the order they are mentioned. Above these was the firmament of the fixed stars, the crystalline orbs, the primum mobile, and last of all, the cœlum empyrium, or heaven of heavens. All these vast orbs were imagined to move round the earth once in twenty-four hours, and also in certain stated or periodical times, agreeable to their annual changes and appearances. Every star was supposed to be fixed in a solid transparent sphere, like crystal; and to account for their different motions, he was obliged to conceive a number of circles called eccentrics and epicycles, which crossed and intersected each other in various directions. And if any new motion was discovered, a new heaven of crystal was formed to account for it. So that, as Fontenelle observes, heavens of crystal cost him nothing, and he multiplied them without end, to answer every purpose.

This absurd system is referred to by Milton, in the 8th book of his Paradise Lost, where, speaking of the dreams of visionary philosophers, concerning the nature and motion of the heavenly bodies, he says,

——————"Or if they list to try
Conjecture, he his fabric of the heavens
Has left to their disputes, perhaps to move
His laughter at their quaint opinions wide
Hereafter, when they come to model heaven
And calculate the stars, how they will wield
The mighty frame, how build, unbuild, contrive
To save appearances, how gird the sphere
With centric and eccentric scribbled o'er,
Cycle and epicycle, orb in orb."

The embarrassment of these circles appeared so great, that Alphonsus, king of Castile, a considerable mathematician of his time, did not scruple to observe that if God had called him to his council when he made the world, he could have directed him how to have done it in a better manner. The thought savours too strongly of libertinism, but at the same time sufficiently exposes the confusion and absurdity of this hypothesis.

But independently of these considerations, this rude system was soon found incapable of standing the test of observation and experiment; and, notwithstanding the opposition of blind and zealous bigots, it has long been rejected by all mathematicians and true philosophers. The planets, Mercury and Venus, are now well known not to include the earth in their orbits; and the comets move through the heavens in all manner of directions, so that they must infallibly have met with continual obstructions, and would, long ere this, have broken all these crystal spheres to pieces, and rendered them totally unfit for the purposes for which they were designed.

The contradictions and perplexities attending the Ptolemaic hypothesis, were indeed so numerous and evident, that it was impossible they should ever be reconciled upon that supposition. But notwithstanding this, mankind were not easily induced to give up their darling prejudices, and embrace the truth, in whatever form she presented herself to them. Many early habits must be corrected, and vulgar prepossessions eradicated from the mind, before we can be brought to reckon the earth as a planet, and to consider this prodigious globe, which, of all things in nature, appears to be the most fixed and stable, to be carried round the heavens with the rapidity of fifty eight thousand miles an hour.

To humour these prejudices, by keeping the earth still fixed in the centre, but at the same time to remove some of the most palpable absurdities attending that doctrine, was the design of Tycho Brahe, who attempted to establish a new system, and to account for the celestial motions by a more plausible hypothesis. This noble Dane, who flourished in the latter end of the sixteenth century, had furnished himself with an excellent collection of mathematical instruments, and, by that means, had made himself too well acquainted with the motions of the heavenly bodies, to imagine their centre to be any where else than in the sun. He was struck with the beauty, simplicity and harmony of the Pythagorean system, which Copernicus had lately revived; but out of respect for some passages of Scripture, which seemed to contradict this doctrine, he set himself about to reconcile his learning with his faith; and, in order that the earth might remain quiescent, he supposed the sun, with all the planets, to be carried about it in the space of a year; whilst these, by their proper motions, revolved round the sun in their several periods.

In this new system of Tycho's, there is some ingenuity, though but little conformity to truth and observation. For having rejected the diurnal rotation of the earth on its axis, he was obliged to retain the most absurd part of the Ptolemaic hypothesis, by supposing that the whole universe, to its farthest visible limits, was carried by the primum mobile about the axis of the earth continually every day. But in this, however, he was abandoned by some of his followers, who chose rather to save this immense labour to the spheres, by ascribing a diurnal motion to the earth; on which account they were distinguished by the name of Semi-Tychonics.

But though Tycho was not happy in establishing a new system, he was yet of great use to astronomy, by his diligence and exactness in making observations for a long series of years. Amongst other things, he discovered the refraction of the air, and determined the places of a great number of the fixed stars, with an accuracy unknown to the astronomers of former times. He likewise demonstrated, against the opinion which then prevailed, that the comets were higher than the moon; and from his observations on this, and the rest of the planets, the theories of their motions were afterwards corrected and improved; so that for these services he will always be celebrated and esteemed by astronomers.

Arts and sciences, like kingdoms and states, have their various changes and revolutions; at some periods shining with uncommon lustre, and at others involved in ignorance and barbarity. Astronomy, having flourished for a considerable time under the auspices of Pythagoras and his followers, was again neglected and obscured for many ages, so that the true system of the world seems to have been entirely forgotten. Instead of consulting the heavens, and collecting the history of nature, succeeding philosophers were ambitious of gratifying their own vanity, by inventing whimsical hypotheses, which had no conformity to fact and experiment. Solid orbs and epicycles were multiplied to answer every appearance, till the universe had lost all its native beauty in their descriptions, and seemed again reduced to a chaos by their unhappy labours.

It was about the middle of the sixteenth century that Copernicus, a bold and original genius, adopted the Pythagorean, or true system of the universe, and published it to the world with new and demonstrative arguments in its favour. (Pl. 1.) Seized with a daring enthusiasm, he laid his hands on the cycles and crystal orbs of Ptolemy, and dashed them to pieces. And, with the same noble phrensy, he took the unwieldy earth, and sent her far from the centre of the system, to move round the sun with the rest of the planets; so that of all the celestial equipage, with which she had been formerly dignified, there only remained the moon to attend and accompany her in her journey.

Europe, however, was still immersed in barbarism and ignorance; and the general ideas of the world were not able to keep pace with those of a refined philosophy. This occasioned Copernicus to have few abettors, but many opponents. Threatened by the persecution of religious bigots on the one side, and with an obstinate and violent opposition from those who called themselves philosophers, on the other, it was not without the greatest solicitations, that he could be prevailed upon to give up his papers to his friends, with permission to make them public. But, from continual importunities of this kind, he at length complied; and his book *De Revolutionibus Orbium cœlestium*, after being suppressed for more than thirty-six years, was at length published, and a copy of it brought to him a few hours before his death.

In this treatise he restored the ancient Pythagorean system, and deduced the appearances of the celestial motions from it in the most convincing and satisfactory manner. Every age since has produced new arguments in its favour; and notwithstanding the opposition it met with from the prejudices of sense against the earth's motion, the authority of Aristotle in the schools, the threats of ignorant enthusiasts, and the terrors of the inquisition, it has gradually prevailed ever since, and is now universally received by all the learned throughout Europe.

Towards the end of the same century also, and about the beginning of the next, those great men Galileo and Kepler particularly distinguished themselves in the defence of this doctrine; and by means of the telescope, which was the invention of that time, made many new and surprising discoveries in the heavens. By applying this instrument to the planets, Galileo first observed, that the phases of Venus were like the monthly phases of the moon; and thence inferred that she revolved round the sun as a centre. He also proved the revolution of the sun on its axis, from the motion of his spots; and by that means rendered the diurnal rotation of the earth more credible. The four satellites which attend Jupiter, in his revolution about the sun, represented, likewise, in miniature, a just image of the great solar system, and rendered it more easy to conceive how the moon might attend the earth, as a satellite, in her annual revolution. In short, by his discovering hills and cavities in the moon, and spots in the sun, he proved, clearly, that there was not so great a difference between celestial and sublunary bodies as philosophers had vainly imagined.

From these discoveries, astronomy began to assume a new form, and most of the celestial phænomena were soon accounted for, according to their real or physical causes. Des Cartes, Gassendus, Cassini, and Newton, employed themselves, with the utmost diligence, in improving and perfecting this science: and the last of these great men, in particular, has established the Copernican system upon such an everlasting basis of mathematical demonstration, as can never be shaken, but must last as long as the present frame of nature continues in existence.

LETTER V.

OF THE SYSTEM OF DES CARTES.

THE active mind of man is naturally fond of investigation; and from contemplating effects, we are insensibly led to enquire into the causes which produced them. After having discovered the vast extent of the creation, and the order, regularity, and harmony of the celestial motions, our next reflections will be, how such a frame began at first to exist, and by what force those prodigious bodies are constantly driven round the sun, and retained in their orbits.

But to prosecute these researches with proper advantage, requires a free and unbiassed mind, invigorated with all the powers of genius and judgment. From the workmanship to trace the Workman; and from viewing the grand machine of the universe, to discover the hidden springs of its motion, and the secret laws of its mechanism and contrivance, is, of all pursuits, the most sublime and interesting, and, perhaps, the highest pitch of knowledge which the human faculties are capable of attaining.

It must not, therefore, be considered as a matter of surprise, that, in the more early ages of the world, when science was yet in its infancy, and the mind of man enslaved and debased by ignorance and a barbarous superstition, a knowledge so exalted and refined should be but imperfectly understood, and but little cultivated.

The priests and magi of the east, who are supposed to have been the first masters of the sciences, involved all their notions in ænigmatical and allegorical representations; so that what was plain and simple, was rendered mysterious and doubtful; and mankind, instead of being made acquainted with nature, and the manner in which she conducts her operations, were amused only with absurd fables and chimerical conceits, which were so far from answering the purposes of instruction, that they served only to impede and retard it. To some of their most favoured disciples and followers they unveiled their mysteries, but the people in general were kept in darkness and the grossest ignorance.

From Egypt and Phœnicia philosophy travelled into Greece, and was there more generally cultivated and diffused; but in a manner equally unfavourable to instruction and improvement. The philosophers of those times, disputatious and obstinate, were more fond of victory than truth; and whilst they contended only to show their ablities, and to display a vain ostentation of learning, men were diverted from pursuing real knowledge, and a talkative philosophy was instituted, which was principally upheld by logical quibbles and sophistical subtilties, that had no relation to fact or experiment, the only sure foundations upon which any system of physics can possibly be supported.

Instead of searching into nature, men retired to contemplate their own notions; and, instead of tracing her operations, gave their imaginations full play; where they ought to have hesitated they decided; and where there was no diffiulty they doubted. What was simple they divided, and defined what was plain; but in what was more intricate, the subterfuges of art were set up in opposition to nature, and captious science against common reason.

A considerable party of old, adopted that monstrous system, which, excluding the influence of a Deity, attempted to explain the formation of the universe from the fortuitous concourse of atoms; and derived the ineffable beauty of things, and even life and thought itself, from a lucky hit in the blind uproar. One sect retained the passive and sluggish matter only, whilst others, more refined, admitted active as well as passive principles, life as well as thought, and taught that every thing was governed by a supreme Mind. Some maintained, that there was no stability of essence or knowledge any where to be found, but that man was the measure of truth to himself in all things, and that every opinion or fancy of every man was true. Whilst others, again, ran into the opposite extreme, and were so sceptical as to doubt even whether they doubted or not.

But to leave these, and a thousand other crude notions, which deserve no remembrance, we will now proceed to consider the more plausible hypothesis of a philosopher of modern times, who has attempted to explain the phænomena of nature by principles less exceptionable than those of the ancients; and has acquired such a reputation amongst his followers, as makes it necessary to examine his doctrine with more particular attention.

Renes des Cartes, a French philosopher, who was born in the year 1596, was the author of this new system, which has been so highly extolled, and considered by many, as the most extensive, and exquisite in its contrivance, of any that had yet been imagined. Endowed with a bold and elevated genius, he scorned to subject himself to the servile drudgery of observation and experiment, but attempted to unveil all the mysteries of nature at once; and thought it beneath him to offer any thing to the world, less than a complete and finished system.

In order to attain this grand purpose, he begins his Principia, by endeavouring to establish a clear and perfect idea of the existence and attributes of the Supreme Being; which he makes to depend upon our inward conviction that such a being actually is; and from this absolute and certain knowledge of the Deity, he attempts to deduce an explication of his works, that by this means we may acquire the most perfect kind of science, which is that of deducing effects from their causes.

From the veracity of the Supreme Being, he infers the reality of material objects, which are represented to us, as existing without us; and, by placing the essence of matter in extension, he concludes, that there can be no such thing as a vacuum, or space void of body or material substances; but that all nature is absolutely replenished, and that there must be an universal plenum.

All self-evident propositions and axioms, are made, by him, to depend upon the mere will and arbitrary choice of the Deity; and, after explaining the formation of matter, and its division into different elements, he next proceeds to show how the universe might have assumed its present form, and may be for ever preserved by mechanical principles.

To account for the motions of the celestial bodies, the sun is supposed to be placed in the centre of a vast whirlpool of subtle matter, which extends to the utmost limits of the system; and the planets, being plunged into such parts of this vortex as are equal in density with themselves, are continually dragged along with it, and carried round their several orbits by its constant circulation. Those planets which have satellites, are likewise the centres of other smaller whirlpools which swim in the great one; and the bodies that are placed in them, are driven round their primaries in the same manner as those primaries are driven round the sun.

Now as the sun turns upon his axis the same way that the planets move round him, and the planets also turn round their axes the same way as their satellites move round them; it was imagined, that if the whole planetary region was filled with a fluid matter, like that before-mentioned, the sun and planets, by a constant and rapid rotation on their axes, would communicate a circular motion to every part of this medium, and by that means drag along the bodies that swim in it, and give them the same circumvolution.

This, in few words, is the celebrated system of vortices, and the world of Des Cartes. The fabric, it must be confessed, is raised with great art and ingenuity, and is evidently the produce of a lively fancy and a fertile imagination. But then, it can be considered only as a philosophical romance, which amuses without instructing us, and serves principally to show that the most shining abilities are frequently misemployed; and will always be found inadequate to the arduous task of forming a complete system of nature, which is not to be expected even from the labour of ages.

The method which he has taken to establish the existence and attributes of the Deity, merely from any abstract notions which we can form of such a being, independently of his works, is also very improper and unsatisfactory. And the making of truth and falshood, right and wrong, to be dependent on his will only, tends to weaken all science and confound its principles.

Whilst he supposes extension to constitute the essence of matter, he neglects solidity, and the inertia by which it resists any change in its state of motion or rest, which principally distinguishes body from space; and, for that reason, the doctrine of an universal plenum, deduced from this definition, is founded upon false principles.

That there is such a thing as a vacuum in nature, or a space void of body, may be demonstrated from a variety of experiments. By means of the air-pump, we can so far exhaust the air from a glass-receiver, that a piece of gold and a feather, being let fall together, from the top of the vessel, shall both descend equally swift, and come to the bottom at the same time: which evidently shows, that the air being taken away, there remains no other matter sufficient to cause any sensible resistance, or that in the least impedes or obstructs their passage.

Upon the supposition, indeed, of an universal plenitude, all motion would be impossible. For whatever be the nature of this materia subtilis, whether dense or rare, the whole must be absolutely immovable and impenetrable; and for a body to pass through such a medium, would be more difficult than for it to pass through a sea of quicksilver, or a rock of adamant.

It was said, by many of the ancient philosophers, that nature abhors a vacuum; and by means of this absurd dogma, and many others of the like nature, they attempted to prove and illustrate the doctrine of an universal plenum, like that of Des Cartes. But this is a bare assertion, unsupported by facts, and is too idle a notion to require any formal refutation. And in nearly the same predicament, are most of the other arguments that have been used in defence of this doctrine. They are all sufficiently exposed, not only by the Torrecellian experiment, and the nature of pumps in general, but likewise from the most obvious phænomena of the constant and free motion of bodies; as well those that are in the heavens, as those that are near the earth's surface, which come continually under our inspection.

The objections which may be brought against his vortices, or whirlpools, are also equally strong and irrefragable; and show clearly enough, the contradictions and absurdities which attend this hypothesis. For if these imaginary vortices carried the planets from west to east, by means of their particular circulations, the comets, which traverse those spaces in various directions, from east to west, and from north to south, could never move according to any determinate law, as they would be constantly impeded and turned out of their course by so many contrary and opposite motions.

Besides which, if it should be allowed, that the comets had never actually passed from east to west, and from north to south, yet nothing would be gained by this concession. For it is well known, that whilst a comet is passing through the neighbourhood of Mars, Jupiter, or Saturn, it moves considerably swifter than either of those planets; and therefore cannot be carried round by the same bed of fluid matter, which is supposed to carry round these planets.

It has likewise been demonstrated by Newton, and others, that let the nature of these vortices be what it may, yet the circulations of the planets, in such a fluid, would never agree with the known laws of their motion, established by all the later astronomers, from repeated observations. But, admitting for a moment that this system of whirlpools was compatible with the phænomena of nature, and the laws of mechanics, yet their cause would be but little better; for no such whirlpools have ever yet been shown to exist. It is not sufficient that an hypothesis accounts for the phænomena; but it must be shown that it is founded in fact, and sanctioned both by reason and experience.

To sum up the whole, it is easy to perceive what must happen to several fluids circulating in contrary directions, and in opposition to each other. They would necessarily be confounded together; and instead of maintaining an order and harmony in nature, would form a chaos, and introduce eternal anarchy and confusion. This alone would at once have exposed the Cartesian system to the utmost ridicule, if a love of novelty, and an habitual disuse of free and impartial enquiry, had not universally prevailed in the world, and made way for its introduction.

This doctrine has been often altered, and mended, since it was first proposed by its author; and, for near a hundred years after, many ingenious men were making their utmost efforts to patch it up and support its credit. But the foundation is too faulty; and the whole superstructure so erroneous, that it were much better to abandon the fabric, and suffer the ruins to remain a memorial to posterity, of the folly of philosophical pride and presumption.

It was upon the principles of the Cartesian philosophy, that Spinoza founded his system of atheism, and thence attempted to defend all the absurdities which naturally attend such a doctrine. And though many of the followers of Des Cartes have endeavoured to show that his system is not favourable to such notions, yet it must be owned that they have but ill succeeded. For if a void be impossible, and matter be infinite, it will evidently follow that matter must be necessary. But if matter be necessary, it must exist of itself, by an absolute necessity inherent in its nature, and antecedent to all things. Matter would therefore be God, and he who maintains these principles, ought, if he reasons consequently, to admit of no other conclusion.

Leibnitz, the great and illustrious opponent of Newton and Clarke, draws, it is true, very different conclusions from this doctrine. From representing the universe as a machine that would proceed for ever, by the laws of mechanism, in the most regular manner, and by an absolute and inviolable necessity, he concludes it to be a perfect work, or the best that could possibly have been made; and contends, that the contrary opinion is derogatory to the wisdom and power of the Supreme Being.

The origin of evil, which has perplexed and embarrassed the philosophers of all ages, he also asserts to be perfectly reconcileable upon this system. Like Plato and Chrysippus of old, he maintains that it never could have been the aim, or first intention of the Author of Nature, and parent of all good, to make men obnoxious to diseases, and other evils; yet, whilst he was producing many excellent things, and forming his work in the best manner possible, other things also arose, connected with them, which were incommodious, and not made for their own sake, but permitted as necessary consequences of what was best.

The perfection of the universe was, indeed, this learned author's darling theme. But after all that he has said upon the subject, though it may perhaps perplex his readers, yet it can never satisfy them. For is it not much more desirable that the Author of the world should be constantly acting in it, and cherishing it by his presence, than that, after having finished his work, he should totally abandon it, and think it no further worthy of his notice or inspection?

It was fit that there should be, in general, a regularity and constancy in the course of nature, not only on account of its greater beauty, but also for the sake of intelligent agents, who, without this, could have had no foresight, or occasion for choice and wisdom in judging of things by their consequences; and, therefore, no proper exercise for their reasonable faculties.

But though the course of nature was to be regular, it was not necessary that it should be governed by those principles which arise from the various motions and modifications of inactive matter, or by mere mechanical laws only; since it would then have been incomparably inferior to what it now is, both in beauty and perfection, and consequently far less worthy of its ineffable Contriver,

——————" Whose mighty hand,
For ever busy, wheels the silent spheres;
Works in the secret deep; shoots, streaming thence,
The fair profusion that o'erspreads the spring;
Flings from the sun direct the flaming day;
Feeds every creature; hurls the tempest forth;
And, as on earth this grateful change revolves,
With transport touches all the springs of life.

THOMSON.

LETTER VI.

OF THE DISCOVERIES OF KEPLER AND GALILEO.

Distinguished above other creatures, by the faculty of reason, and the superiority of his nature, man is still the slave of prejudice and opinion, prone to error, and subject to continual delusion. Truth and science advance by slow degrees; one age destroys the labours of another, whilst conjecture and hypothesis supply the place of argument and demonstration. Nature performs her operations constantly before our eyes, and has furnished us with the means of tracing their causes and connections; but the mind, debased by indolence, or bewildered by superstition, regards these astonishing scenes with indifference, and considers all attempts to investigate their causes, as the effects of a presumptuous and daring impiety.

From the time of Pythagoras to the sixteenth century, when the true system of the world was again revived by Copernicus, the vulgar opinion of the motion of the heavens, and the immobility of the earth, was generally received; and time, instead of discovering its fallacy, served only to strengthen and confirm it. To the authority of men of acknowledged reputation for their learning and talents, the example of ages was added; and thus error was transmitted from one generation to another, with additional prevalence. Plato and Aristotle were referred to as the arbiters of every dispute, from whose authority there was no appeal;

and when reason and argument failed, the aid of religion was called in to their support.

To dissent from the opinions of Aristotle, or those which his ignorant interpreters had given him, was looked upon as a heresy that called for the loudest anathemas of the church. And so venerable and sacred were those doctrines held, that whoever presumed to controvert them, was considered as an impious innovator, that attempted to remove the land-marks both of faith and reason. To his opinions, in all religious controversies, both parties appealed; from these the Papist supported all his absurdities, and the Protestant drew arguments for their refutation.

Error being thus established by time, superstition and prejudice, the face of nature was covered with a veil of awful obscurity, and the progress of useful knowledge effectually prevented. The highest ambition of some of the most eminent men of the age, was to prove the truth of that by sophistical arguments, which reason and science affirmed to be false. But such fantastical opinions could not always prevail; time will constantly be found to produce some lovers of truth, who will penetrate through clouds of error to attain it. After a long night of the most profound darkness, Copernicus again revived the true system of Pythagoras and his followers, and showed it to be the only one which is agreeable to reason and observation.

But the greatest champion of useful learning that had hitherto appeared in the world, was Sir Francis Bacon, Lord Verulam, who by his superior knowledge and eminent abilities, overthrew the establishment of ignorance and error, and convinced the infatuated world, that opinions supported by the authority of Aristotle and antiquity, were not infallible. By clear incontrovertible arguments, supported by reason and science, he refuted their errors, and showed that the only method of obtaining a true knowledge in philosophy was by observation and mechanical experiments.

It was now that men began to discern truth from falsehood, and, disregarding hypothesis and conjecture, to investigate the works of nature from their effects and appearances. Matter and motion were observed to constitute the principal phænomena of the visible world; and as the properties and affections of these are the subject of mechanics, that science grew into esteem, and was assiduously cultivated by the most eminent mathematicians in Europe.

By applying mathematical reasoning to mechanical experiments, Sir Isaac Newton established the truth of the ancient Pythagorean system; and upon this foundation raised the superstructure of that philosophy, which, whilst all other systems sink into ruins, and little more than their inventors names are remembered, will remain for ever firm and unshaken: for being once demonstrated to be true, it must eternally remain so, as nothing can alter it but the utter subversion of the laws of nature, and the constitution of things.

The method of admitting nothing into philosophy, unconfirmed by experiment or demonstration, required too great a perseverance for the flighty imagination of those, who, contenting themselves with the semblance of truth, expatiated in the wilds of fiction. For a work of this kind, the genius and industry of a Newton was alone sufficient, who chose rather to acquire a little true knowledge of nature from practical investigation, than to aim at a general comprehension of all her operations, upon the weak foundation of probability and conjecture.

But in order that the genius of this extraordinary man may appear in its true light, it will be necessary to give you some account of the labours of those, who, since the time of Copernicus, had been preparing the way, and laying the foundation for his discoveries and pursuits; which information is the more necessary, as many persons, who have but a slight acquaintance with the progress of astronomical learning, are apt to entertain very erroneous opinions upon the subject. As the labours of many are attributed to one Hercules, so, by a like exaggeration, Sir Isaac Newton is said to be the author of all the discoveries and improvements which have ever been made in this science. But as his merit is too great to stand in need of such extravagant additions, it will be proper to divest him of this false glory, by ascribing to him that only to which he has an undoubted claim.

The first founder of modern astronomy was Kepler; and if it be the privilege of genius to change received ideas, and to announce truths which had never before been discovered, he may justly be considered as one of the greatest men that had yet appeared in the world. Hipparchus, Ptolemy, Tycho Brahe, and even Copernicus himself, were indebted for a great part of their knowledge to the Egyptians, Chaldeans, and Indians, who were their masters in this science: but Kepler, by his own talents and industry, has made discoveries, of which no traces are to be found in all the annals of antiquity.

This philosopher was born at Wiel, in the province of Wirtemberg in Germany, on the 27th of December, 1571, and was one of the most zealous partizans of the Copernican system that had hitherto appeared. In 1596 he published a large work upon the proportions and dimensions of the orbits of the planets, which coming into the hands of Tycho Brahe, he advised him to apply himself to observation, before he attempted to discover the laws of nature; and assured him, if he would do this, he would find more truth in his hypothesis than in that of Copernicus. He perceived the genius of Kepler, and wished for nothing more earnestly than to have him for his disciple.

I shall not enter into a detail of the reasons which are given by Kepler for arranging the planets according to the order of the five regular bodies, nor of the mysterious harmony which he finds between celestial and sublunary things. He was a man of a warm imagination, which led him into many absurdities; and it was the folly of that age, to mix sacred things with those which have no connection with them. He tells us in his *Mysterium Cosmographicum*, that he looked upon three grand things as deserving his particular attention; the firmament of the fixed stars, the sun, and the enormous interval which separates them; these appeared to him to be a symbolical representation of the Trinity; and the spherical figure of the universe, which comprehends the whole, he considered as an image of the Supreme Being, whose immensity envelops all things. Plato called God the eternal geometer; and Kepler, worthy to be the successor of so great a master, believed that certain properties of numbers and geometrical figures had a hidden analogy to all the operations of nature.

Besides entertaining a number of chimerical ideas of this kind, he had also a secret attachment to astrology; and in his treatise entitled *De Stellâ Novâ*, has offered a very singular defence of this fallacious doctrine. He asserts, that all the great events and revolutions of the world have an intimate connection with the conjunctions of the planets, and accounts for their influence by comparing it with the action of objects upon our senses. "The stars," he observes, "act upon terrestrial things in the same manner as light acts upon the eye, sound upon the ear, or heat and cold upon the sense of feeling." From this explication, which has nothing to recommend it but its novelty, it is easy to perceive upon what foundation the dreams of astrologers are supported.

But from these absurd reveries, which were mostly the follies of his youth, he soon passed to objects more worthy of his attention. His first works were only the amusements of his leisure hours; but in contemplating his powers, he found himself destined for much greater things. He was led, by an invincible impulse, to the study of philosophy; and no operation of nature ever attracted his notice, but he was immediately desirous of searching into its cause, and attempting its explication. His observations upon the nature of refraction, parallax, and many other subjects of equal importance, are sufficient proofs of his penetration and judgment; and from his uniting the science of optics with that of astronomy, we may form an estimate of his genius and abilities.

In the true system of the world, as restored by Copernicus, the astronomer, having no longer a stationary situation upon our globe, is obliged to transport himself to the centre of the sun, and to observe the celestial motions from a point which is only accessible by the imagination. It was from this point that Kepler contemplated the spectacle of the heavens, and saw the fallacy of a doctrine, which all the astronomers before his time had considered as infallible. The apparent simplicity of nature in all her operations, had seduced them to imagine, that a circular and uniform motion of the heavenly bodies was a necessary consequence of this law. But this opinion, however reasonable it might seem to others, appeared to him as an idle conjecture; and from the observations of Tycho, and his own industry, he soon proved it to be erroneous and ill-founded.

That the orbits of the planets were not circular, might, indeed, have been easily conjectured from many circumstances. Their conjunctions, oppositions, and other mutual situations, not returning again in the same time; and their distances from the sun appearing to be greater or less in different parts of their orbits, were sufficient indications of the fallacy of this doctrine. But so firmly were astronomers persuaded that their motions must be circular, that they attributed these irregularities to certain optical delusions, and invented cycles and epicycles without number, to account for every appearance.

Kepler was the first who perceived, that all motion is naturally performed in a straight line; and that when a body moves in a circle, or any other regular curve, it must be acted upon by two forces, one of which sets it in motion, and another that opposes this motion, and changes its direction. From these principles, and a number of calculations equally difficult and laborious, he proved, that the planets must revolve in elliptical orbits, the sun being placed in one of the foci; and that their velocities are such, that a line drawn from the sun to a planet, and supposed to move with it, will describe equal areas in equal times.

In order to illustrate this by a figure, (Pl. III. fig. 1.) let ADBC be an ellipsis, whose transverse or longest diameter is AB, and its conjugate or shortest diameter CD; then the two foci F, f, are points so situated, that if right lines be drawn from them to any point G in the curve, the sum of those lines will always be equal to the transverse diameter AB. And if the sun be placed in the focus F, and a planet be supposed to revolve round him in the curve BCAD, it will move in such a manner, that a line drawn from it to the sun, will describe equal areas in equal times. That is, if the line FG, drawn from the sun F to the planet G, describes the area or space BFG in a month, it will describe an area GF g equally large the next month; and so on through its whole revolution.

The distance between the centre of the ellipse O, and one of its foci F, is called its eccentricity; and the two extreme points A and B of the transverse diameter, are called the apsides. If the focus about which the equal areas are described, be at F, the point A, nearest that focus, is called the lower apsis, the point B the upper apsis, and the diameter AB the line of the apsides. When a planet, in revolving round the sun, is at its nearest distance from him, as at A, it is said to be in its perihelion; and when at its furthest distance, or at B, it is said to be in its aphelion, the mean distance being FC. In like manner, when the earth is in its perihelion, the sun is said to be in its perigee; and when the earth is in its aphelion, the sun is said to be in its apogee.

But let us leave the further explanation of these terms for the present, and return again to Kepler. This excellent astronomer, having firmly established the law before-mentioned, procceded to the consideration of another, of no less importance. He had happily conceived, that there might probably be some proportion between the times of the revolution of the planets, and their distances from the sun; and by prosecuting the enquiry, which this idea suggested, his success was equal to his most sanguine expectations. By calculations founded on a series of the most accurate observations, he discovered, that the squares of the times in which any two planets complete their revolutions in their orbits, are proportional to the cubes of their mean distances from the sun.

To illustrate this rule by an example: Venus, for instance, revolves round the sun in 224 days, and the earth in 365; and the mean distance of the earth from the sun is ninety-three millions of miles. Hence, according to Kepler, as the square of 365 is to the square of 224, so is the cube of ninety-three millions of miles, to a fourth number, which is the cube of Venus's mean distance from the sun; and if the cube root of this number be found, it will give about sixty-eight millions of miles for her real mean distance; so that, by this rule, if the times of the periodical revolutions of the planets be known, and the mean distance of any one of them from the sun, the mean distances of all the rest may be determined by a simple proportion. Which rule is not only applicable to the planets, but is also equally true with respect to their satellites or attendants; the moons of Jupiter and Saturn being found to follow the same law in revolving round their primaries, which is observed by those primaries in revolving round the sun. (*e*)

(*e*) For a full account of the discoveries of Kepler, the reader is referred to a very ingenious work, lately published

These are the discoveries by which Kepler enriched the science, and obtained an immortality of renown: but it must be observed, that he who had subjected the planetary motions to invariable laws, was unable, with all his penetration, to find out the reason of them. Nature had shown him some of her most secret operations, but a more complete knowledge of them was reserved for Newton. Among a number of ingenious guesses which he has made upon this subject, some are as novel as they are singular. He considers the stars and planets as the inhabitants of ether, which live and move in that element like butterflies in the air; or as plants and animals which spring from the bosom of the earth, to embellish it by their existence, and afterwards render back, by death, the fecundity that nourished them.

That such extravagant dreams should be found on the side of such sublime truths, is, as a certain writer observes, a matter not to be wondered at; a man may be a great genius with regard to calculations and experiments, and yet make a wrong use of his reason in other respects. There are minds which stand in need of geometry to support them, and fall when they endeavour to proceed of themselves. It must be remembered, however, to the honour of Kepler, that his errors were such as usually attend a quick and vigorous conception; and that

by Dr. Small, on this subject, where he will find a variety of useful information, beyond what is to be met with in any of our modern treatises on Astronomy.

some of his conjectures were as grand and philosophical, as others were whimsical and absurd.

His hypothesis for ascertaining the different densities of the sun and planets, according to their distances from the centre of motion, is an instance of his penetration and judgment which deserves to be mentioned. He conceived that the heaviest bodies in our system, must be those which are placed nearest the sun; and as he was always desirous of rendering his ideas as familiar as possible, he illustrates them, in this instance, by the following example. The density of Saturn may be compared to that of a diamond; Jupiter to a loadstone; Mars to iron; the Earth to silver; Venus to lead; Mercury to quicksilver; and the Sun to gold, which is the heaviest of all substances yet known, except platinum. Where it is to be observed, that excepting the density of the sun, this rule differs but little from the truth; and though it was founded upon false reasoning, it was nevertheless a happy conjecture. The time was not yet come for philosophers to weigh the celestial bodies, and to estimate with exactness their different densities.

This great man, whose whole life was so gloriously employed in cultivating and improving the sciences, had his last days embittered by all the horrors of poverty and distress. A small pension, which was scarcely sufficient for his subsistence, was frequently withheld or unpaid; and the trouble and vexation this occasioned him was so great, that it obscured his genius, and finally put a period to his existence. He died on the 15th of November

1631, in the fifty-ninth year of his age, leaving nothing for his wife and children, but the glory of his name, and the fame which he had so justly acquired: but as these were insufficient to relieve his own wants, they could afford but little comfort to a helpless widow and her wretched offspring, whose indigence is said to have been such, that they had not even the common necessaries of life.

Whilst Kepler, in Germany, was tracing the orbits of the planets, and settling the laws of their motions, Galileo, in Italy, was meditating upon the doctrine of motion in general, and investigating its principles. This philosopher was born at Pisa, in the year 1564, and began his improvements in mechanics, by banishing from the science those ridiculous distinctions which had been made by Aristotle and his followers, between light and heavy bodies, motions natural and violent, rectilinear and circular. He showed, both by demonstration and experiment, that, in a space void of air, all bodies whatever, fall through equal heights in equal times; and that a body impelled by two forces, acting in the direction of the sides of a parallelogram, will follow the direction of neither, but proceed in the diagonal, and describe it in the same time, as by the action of one of the forces alone it would have described one of the sides.

These principles he also found to be equally applicable to the motion of all kinds of projectiles. A ball or shell being thrown from the mouth of a cannon, is under the influence of two forces, which, by their joint action, regulate its motion, and determine its direction: one of these forces is that of the powder, by which it endeavours to move continually forward in a straight line; the other is that of its gravity or weight, which inclines it to descend, and fall towards the ground; and from the composition of these two forces, Galileo demonstrated that the curve described by the ball would be that of a parabola. Tartalia had before remarked, without assigning any good reason for his assertion, that a ball would be thrown to the greatest distance, when the piece made an angle of forty-five degrees with the horizon; this rule was not only confirmed by Galileo, but extended still further, by his proving that at all angles equally above and below forty-five degrees, the range would be the same.

The next subject, which engaged his attention, was the phænomenon of falling bodies, and the law of their acceleration. Every attentive mind must have observed that a stone, or any other heavy body, in falling from a certain height, acquires a greater velocity the nearer it approaches the earth; but before the time of Galileo, no philosopher had been able to ascertain the exact proportion of its celerity, in the different instants of its descent. He was the first who determined that the velocities in this case, are always proportional to the times; and the spaces passed through to the squares of those times: that is, in a double time, the body will have acquired a double velocity; in a triple time, a triple velocity, &c; and that, in a double time, the body will have passed through a space four times as great as in a single time; in a triple time, through a space nine times as great; and so on.

Galileo considered nature as the sole agent of the Supreme Being; and that sagacious observance of her operations, which first led him to this useful discovery, was the means of conducting him to another of equal importance. Being with some company in a room, where a lamp was suspended from the roof of the building, this object, which was unnoticed by the rest of the spectators, afforded him a subject of the most profound meditation. He observed that all the vibrations of the lamp, whether great or small, appeared to be performed in the same sensible time; and from this circumstance, simple as it may seem, he is said to have discovered the isochronism of the pendulum; and that a long pendulum moves slower than a short one, according to a certain invariable proportion: by which means he obtained a new instrument for measuring short intervals of time with greater exactness than could be done by clocks, or any other method then in use.

About the time of these discoveries, which were afterwards so fruitful in the hands of Huygens and others, we may place the invention of the telescope; an instrument so singular in its nature, that before its actual construction, the mind could not have conceived such a contrivance, or imagined it to be possible. A lucky incident is said to have effected, what philosophy might have sought for in vain: the children of one Zachariah Jansen, a spectacle-maker of Middleburgh in Holland, being at play in their father's shop, happened, by chance, to place a convex and a concave glass in such a manner, that in looking through them at the weather-cock of the church, it appeared to be nearer, and much larger than usual. The surprise they expressed at this circumstance, exciting their father's curiosity, he examined the same object himself, and finding what the children said to be true, improved the hint, by fixing the glasses upon a board, that they might be always ready for observation.

A discovery attended with so many obvious advantages, could not long be kept a secret; the news was soon conveyed to all the learned throughout Europe. Galileo was at Venice when he first heard of the invention; and being only informed, that by the combination of two glasses, the apparent magnitude of objects might be considerably augmented, he soon discovered the whole secret. Instead of the board employed by Jansen, he made use of a tube, and, at his first essay, produced an instrument which made the diameter of objects appear three times greater than to the naked eye. At his next trial he magnified the diameter of an object about eight times, and soon after this thirty times; which is nearly the greatest perfection, that this kind of telescope is capable of.

Thus was Galileo, and, by his means, mankind in general, put in possession of two new organs of power and perception; one, for measuring small, and almost imperceptible portions of time, with ease and exactness; and the other, for subjecting those things to our observation, which by their smallness or distance would otherwise have escaped the senses. M. Montucla, who has examined the subject with impartiality and judgment, has given the invention of the telescope to Jansen; and, from the strength of the evidence, it appears highly probable that he was the first who saw the effects that such an instrument would produce. But if he be the real author of an invention, who, from a knowledge of the cause upon which it depends, deduces it from one principle to another, till he arrives at the end proposed, the whole merit of the discovery is due to Galileo; the telescope in the hands of Jansen, was a rude instrument of mere curiosity, pointed out to him by chance; but Galileo was the first who constructed it upon principles of science, and showed the practical uses to which it might be applied.

The discoveries he made, by means of this instrument, were as new as they were surprising. The face of the moon appeared full of cavities and asperities, resembling vallies and mountains: the sun, which had generally been considered as a globe of pure fire, was observed to be obscured by a variety of dark spots, which appeared upon different parts of its surface; a great number of new stars were discovered in every part of the heavens; the planet Jupiter was found to be attended with four moons, that moved round him in the same manner as our moon moves round the earth; the phases of Venus appeared like the monthly phases of the moon; and, in short, every observation he made, furnished him with a new proof in favour of the Copernican system, and served to show that there is not so great a difference between celestial and sublunary nature, as the philosophers of antiquity had vainly imagined.

Galileo was now in the seventieth year of his age, and but for the persecution of those who ought to have cherished and revered him, his life might have been as happy to himself as it was beneficial to mankind. But in the midst of his researches and discoveries, which he prosecuted with the greatest assiduity, he was summoned before the tribunal of the inquisition, as a man of the most obnoxious and dangerous principles; and on the 22d of June, 1663, the following arret was pronounced against him, by seven cardinals, who were appointed his judges. And as it is a curious specimen of catholic infallibility; I shall give it you as it stands in the work from which it was extracted.

"Soutenir qui le soleil immobile et sans mouvement local, occupe le centre du monde; est une proposition absurde, fausse en philosophie, et hérétique, puisqu'elle est contraire au temoignage de l'écriture. Il est également absurde et faux en philosophie de dire que la terre n'est point immobile au centre du monde; et cette proposition, considérée théologiquement, est au moins erronnée dans la foi." After this, the following abjuration was dictated to him, which he was obliged to sign: "Moi Galilée, à la soixante-dixieme année de mon âge, constitué personnellement en justice, etant à genoux, et ayant devant les yeux les saints évangiles, qui je touche de mes propres mains, d'un cœur et d'une foi sincere, j'abjure, je maudis et je déteste les absurdités, erreurs, hérésies, &c."

For a venerable old man, who had enlightened Europe by his discoveries, to be seen upon his knees before an assembly of haughty, ignorant bigots, renouncing, by their compulsion, those truths which nature and his own conscience affirmed to be incontrovertible, was a spectacle that cannot be thought of without indignation and abhorrence. Cardinal Bellarmin, one of his judges, had before threatened him with the vengeance of the church, if he should presume to progagate his heretical opinions any longer, either by discourse or writing; and as Galileo had not paid an implicit obedience to this mandate, he was now proceeded against as a despiser of civil as well as sacred authority, and was accordingly sentenced to be confined in the prison of the inquisition, during the pleasure of the inquisitors.

This sentence, however, was afterwards changed into the milder one of being confined in the small village of Acetri in Tuscany during his life. Here he pursued his studies with as much avidity as ever, and made several new discoveries and improvements in his favourite science; but soon after this, whilst he was engaged in his observations upon the liberation of the moon, he was suddenly deprived of his sight, and the heavens being now shut upon him, the book of nature was no longer subject to his inspection. His age advancing, and his infirmities increasing, the grave at length received him from his persecutors; he was buried in the tomb of his ancestors; his disciples, who loved him in his life, honoured him in death; and his name was transmitted to posterity with the fame he had so justly acquired.

The celebrated geometer Viviani, who had been one of his most favourite pupils, showed a zeal for the glory of this great man, that is without an example; the most tender and dutiful child could not have a greater affection for his parent than he had for his illustrious master. He considered it as the pride of his life that he had been one of his last disciples; and when Louis XIVth gave him a pension, and appointed him one of the foreign associates of the Academy of Sciences at Paris, he built a house at Florence, and, after paying a tribute of gratitude to the French monarch, erected a magnificent monument to his beloved master Galileo.

LETTER VII.

OF THE NEWTONIAN SYSTEM, AND DISCOVERIES.

In all ages of the world, mankind in general have been nearly the same: the powers of the mind are various; but there are certain prescribed bounds which it is the lot of but few to pass. The multitude were certainly designed for manual labour and industry, and their minds are, by custom, made conformable to their employments. Intent upon the common concerns and business of life, they have but little leisure, and less inclination, for mental improvement. This is the wise designation of Providence. The earth must be cultivated to support its inhabitants; a general refinement would be as prejudicial as a general barbarity.

Humanity, however, has higher privileges. Arts and sciences, legislation and morals, are absolutely necessary to the due regulation and order of civil society. And that a knowledge of them may be properly distributed, the Author of Nature has, at different times, raised up some great and illustrious genius to enlighten and instruct us. In religion, our most momentous concern, he has condescended to give us a divine guide; and in every art and science, we have had preceptors of eminence proportionate to the importance of the subject.—Every thing bears the marks of omniscience: wherever we turn our eyes, we perceive a presiding intelligence, that informs and regulates the whole.

To enumerate the most shining characters of the kind here mentioned, and to show the discriminating excellence and utility of the several pursuits in which they were engaged, would be a matter of much difficulty, and foreign to our purpose. The subject upon which we are, at present, to employ our attention, is physical astronomy; and we are now to consider the genius and doctrines of a man, who, in his philosophical character, appears to have been endowed with superior faculties, in order to dissipate the accumulated mists of ignorance and error, and to lead us to a knowledge of those truths, which the wisdom of ages had been unable to discover.

The person to whom we owe these obligations, is the illustrious Newton, who was born at Wolstrop in Lincolnshire, on Christmas-day 1642. His father was the reduced descendant of a noble family; but the genius of his son eclipsed all the splendor of hereditary titles and honours. Of his juvenile studies we have but little knowledge, none of his first attempts, or essays, having ever appeared. He seems to have been an inventor rather than a student; and to have entered at once into the depths of science, without attending to the usual gradations. It was on this account that Fontenelle applied to him the following idea of the ancients, concerning the unknown source of the majestical river that fertiles Ægypt: Il n'a pas été permis aux hommes de voir le Nil foible et naissant.

Every science upon which this great man employed his attention, received a new form from his hands, and was carried to a degree of perfection unlooked for by the ancients. In the course of a few years he had destroyed the works of ages, and erected an edifice of his own, which will be as durable as the fabric of nature itself. Algebra, geometry, mechanics, optics, chronology, philosophy and astronomy, began now to assume an unusual splendor and dignity; and by his improvements and discoveries, were rendered prodigiously more extensive and important. The method of Fluxions, in particular, was entirely his own invention; which alone was sufficient to have rendered his name immortal. The exquisite subtilty of this doctrine is such, that the powers of the human mind seem inadequate to a higher pursuit. Any thing beyond it, must be the science of pure intelligence.

From a genius like this, what had we not to expect? His account of the universe, and the laws by which it is regulated, is founded upon the most indubitable principles of reason, science, and observation. We are no longer compelled to wander through the intricate mazes of hypothesis and conjecture. Nature appears again in all her primitive simplicity. Newton has dissolved the chaos, and separated the light from the darkness. His inimitable work, The Mathematical Principles of Natural Philosophy, contains the true astronomical faith, which may be strengthened and improved by farther enquiries, but can never be shaken or destroyed.

To give a perspicuous and methodical account of his various investigations and discoveries, would be a work of great difficulty, and what, from the incompetency of your present acquirements, could afford you but little instruction. Confining myself, therefore, to those which are the most familiar and interesting, I shall begin with his speculations upon gravity and attraction, and relate from the authority of his commentator and friend, Dr. Pemberton, the simple incident which is said to have given birth to them.

About the year 1666, or the twenty-fourth year of his age, he retired from Cambridge into the country, in order to avoid the plague, which, at that time, raged with great violence; and sitting one day in an orchard, an apple, by chance, falling from one of the trees, caused him to enter into a number of reflections. The phænomena of falling bodies particularly engaged his attention; and pursuing the ideas which presented themselves to his mind, he carried his researches from the earth to the heavens, and began to investigate the nature of motion in general. Because there is motion, he observed, there must be a force which produces it; but what is this force? That a body, when left to itself, will fall to the ground, is known to the most illiterate; but if you ask them the reason of its doing so, they will consider you either a fool or a madman: the circumstance is too common to excite their surprise, although philosophers are so much embarrassed with it, that they find it almost inexplicable.

Let us follow Newton, and examine this question a little farther. Does the cause of weight or gravity exist in the bodies themselves, or out of them? It seems natural to conclude, that the propensity which all suspended bodies have of falling to the earth, exists in the bodies themselves. When I take a stone, and let it drop from my hand, it falls immediately to the ground; and would fall still farther, if there were a hole in the earth, and nothing prevented its passage. And the same thing happens to all other bodies, with which we are acquainted: there is no material substance, either great or small, but what will fall towards the earth the moment it is disengaged, and free from all outward impediments.

In like manner it may be observed, that when a stone or any other body is placed upon a table, it presses the table with the same force, by which it would, if left to itself, fall to the ground. And when a body is suspended at the end of a string, the force that pushes it downwards stretches the string, and if it is not sufficiently strong, will break it. From which circumstances it plainly appears, that all bodies press with a certain force against the obstacles which support and hinder them from falling; and that the degree of force, in either case, is precisely the same with that, which in a free space would bring them to the ground.

The cause of this propensity in all bodies to fall to the earth, be it what it may, is called gravitation or attraction; and when a substance is said to be heavy, nothing more is meant than the tendency it has to fall to the ground; or the force by which it presses upon any other body that supports it. The weight and gravity of a body may, therefore, be taken for the same thing; as both the one and the other expresses the force by which the body is impelled towards the earth, whether this force exists in the body itself, or out of it.

With this property of bodies, obvious as it is, the ancients were very imperfectly acquainted. They believed that there were substances, such as vapours and smoke, that by their nature were light, and would for that reason ascend This notion, however, as well as that of absolute levity in general, is now known to be a mistake, and without the least foundation: for in an exhausted receiver, or a space void of air, all bodies whatever, smoke or a stone, a piece of gold or a feather, fall from the top to the bottom in the same time. The distinction, therefore, between light and heavy bodies, is merely relative, as they are of the same nature, and have all a like propensity to fall to the earth.

Neither can there be the least doubt but that gravity is a sort of force: for whatever is capable of putting a body in motion is properly so called. But in all forces, there are two things to be considered; the direction in which they act, and their intensity, or power. With respect to the direction of gravity, we are sufficiently assured, both by reason and experience, that a body, in falling, moves towards a point which is in, or near, the centre of the earth; or, rather, in a straight line that is perpendicular to its surface. The intensity, or power of gravity, is also proportional to the weight of the body under consideration; those which are the heaviest, or that weigh the most, being always observed to descend with the greatest force; and those that weigh the least, with the least force: so that the weight of every body may always be considered as the just measure of its gravity, or the force by which it is made to fall towards the earth.

It may be asked, if the same body, being conveyed to different places upon the earth's surface, will always have the same weight? Those who have superficially considered the subject, will certainly imagine this to be the case; but by numberless experiments, the truth of which cannot be doubted, it is easy to prove the contrary. The weight of a body under the Equator is less than at either of the Poles; and in every other situation, it varies in a certain proportion to the latitude of the place; which is occasioned by the oblate spheroidical figure of the earth, as will be noticed in a future letter. This difference, however, is not to be discovered by means of a balance, or the scales which are usually employed upon these occasions; because the weight, against which the body is opposed, is subject to the same variation. The method by which it has been determined, is by observations made on the vibrations of pendulums of equal lengths, which are found to move swifter at London or Paris, than under the Equator.

These are but the first links in the chain of Newton's ideas: let us follow him a little farther. —The earth is a globe, and gravity acts perpetually in straight lines which are perpendicular to its surface. Suppose a hole could be bored through it, and that a body was placed at the centre, what would be its weight? Evidently nothing: it would remain in the situation in which it was placed, unsuspended and unsupported; since in this situation, being equally acted upon on all sides by the same attractive force, it can have no tendency to move either way, and will therefore remain at rest, and be without weight. For the same reason, if a body was dropped into this orifice from the earth's surface, the velocity acquired, by the repeated impulses of gravity during the time of its fall, would carry it to the opposite extremity of the opening, from which it would again return, and continue to move backwards and forwards for ever, if the medium had no resistance.

Since, therefore, a body, when placed at the centre of the earth has no weight, we should be led to conclude from analogy, that, in descending towards the centre, its weight must be successively diminished; for it is not easy to conceive, that the gravity of a heavy body can change immediately from a certain fixed quantity to nothing. And this doctrine, notwithstanding the impossibility of submitting it to the test of experiment, is not only reasonable in itself, but it admits of the most rigorous demonstration. Newton, in his Principia, has ascertained this gradual diminution of weight, and calculated its precise proportion; which, at all distances below the surface of the earth, he found to be proportional to the distance from the centre.

That such a diminution of gravity, indeed, must of necessity take place, is evident, if we consider, that when a body is placed below the surface of the earth, it will be acted upon upwards by the attractive power of the part above it, which will therefore be opposed to the same power in the parts below, and consequently the whole action downwards will be the difference of those two forces; which, when the body is supposed to be at the centre, will of course be nothing, being then equally acted upon in both directions, and therefore it will remain at rest, as was before stated.

If now we leave the internal recesses of the earth, and extend our researches to the heavens; we shall still find a diminution of gravity, but decreasing by a different law; the cause of which is not however so obvious as in the former instance. Indeed all that can be said on this head is, that that the fact has been ascertained from observation, but the cause of it is as little understood as that of gravity itself. The truth of facts, however, is not weakened because their causes are unknown; and Newton has shown in the most satisfactory manner, that the gravity of bodies, above the earth's surface, continually diminishes as the squares of their distances from the centre increase: or, which is the same, that the forces are as 4 to 1, when the distances from the centre are as 1 to 2; as 9 to 1; when the distances are as 1 to 3; and so on.

From this account you will readily perceive, that gravity is a certain force which acts upon all bodies, and gives them a tendency to fall towards the centre of the earth: and that this force, whatever it may be, acts most strongly upon the earth's surface; being subject, either in ascending or descending, to continual diminution. How then does it appear, that gravity, or weight, is an inherent and necessary property of body? It increases or diminishes perpetually, according to a certain proportion of the distance from the centre; but what is permanent and essential admits not of such different and various mutations. You see then that weight is not so necessarily connected with matter, as, from a slight consideration of the subject, you would naturally imagine.

These were probably Newton's first reflections upon the nature of falling bodies. We shall now see what use he made of them, in applying them to the celestial motions. He soon perceived that the force of gravity was not confined to the surface of our globe, being found to act with the same energy at the greatest heights to which we can ascend, and therefore he conceived it might probably extend as far as to the moon, and be the means of retaining her in her orbit. The conjecture was happy; and, by the following application of it, he was presently enabled to prove its validity. Imagine the moon, at the first moment of its creation, to have been projected forwards, with a certain velocity, in a straight-lined direction; then, as soon as it began to move, gravity would act upon it, and impel it towards the centre of the earth. But as a body impelled by two forces will follow the direction of neither, the moon, so circumstanced, would neither proceed directly forwards, nor fall directly downwards, but keep a middle course, and move round the earth in a curvilinear orbit.

This idea will be more fully illustrated, by attending to the motion of a shell, or any other projectile. A ball discharged from a piece of ordnance, in an horizontal direction, does not fall to the ground till it has proceeded to a considerable distance; and if it be projected from the top of a high mountain, it will fly still farther before it comes to the earth. Increase the force, and the distance will be augmented accordingly. And thus, in imagination at least, we can suppose the ball to be discharged with such a velocity, that it will never come to the ground, but return again to the place from which it set out; and so proceed on again, and circulate continually round the earth, in the manner of a little moon.

Newton did not stop here: he began to generalize the problem, and by means of his mathematics, soon came to this important conclusion. A body which moves in a curve, round a fixed point; by virtue of a force directed to that point, describes equal areas in equal times. This is a law of nature which had before been discovered by Kepler from observation. The supposition, therefore, that the moon is under the influence of such a force, is confirmed both by science and experience; and every improvement which has since been made in the theory of her motion, has been derived from these principles.

It was likewise discovered by Galileo, that, supposing gravity to act in parallel lines, a body projected through the air, with any force whatever, would describe a curve which is called a parabola, if the medium had no resistance. But Newton, whose genius soared above petty distinctions, extended this problem, and made it more general. He no longer considered the falling body as having a limited distance, nor the force of gravity as acting in parallel lines; but regarding the centre of the earth as the centre of attraction, and taking into consideration the lateral uniform velocity of the projectile, he proved that it would move round the earth in an elliptical orbit, having the centre of the earth for one of its foci. So that the projectile, in this instance, may be considered as a moon, moving round the earth, or as one of the satellites of Jupiter or Saturn, moving round those planets; the circumstances, in either case, being exactly the same.

That the moon is actually under the influence of gravity, and moves by means of that force, may be shown as follows: it can readily be computed, that the moon is deflected from the tangent of her orbit, at every point of the curve $16\frac{1}{12}$ English feet in a minute, or 60 seconds of time; and, therefore, if the moon was deprived of the impulse by which she has a tendency to move in a right line from west to east, and the central force only remained, she would fall towards our globe, and describe the above-mentioned space in the first minute of her descent.

This being ascertained, Newton compared the space which would thus be described by the moon at her present distance, with that which would have been described by her, or any other heavy body in the same time, near the earth's surface, as determined by Galileo from actual experiment; and found, that in the latter case, the space described would be $3600 \times 16\frac{1}{12}$ feet. Then, comparing the distance of the centre of the earth from the surface, or the radius of the earth, with the distance of the moon from the same centre, which was known to be equal to 60 of those radii, he found that the force of gravity at the earth's surface, was to its force at the distance of the moon, as 60^2 to 1; so that the force decreases as the square of the distance increases. And in a similar manner, he found that the same law obtained with respect to all the other planets; whence he concluded, that they must be acted upon by gravity in the same manner, and that the whole universe is governed by the same laws; for so exact a conformity, or rather such a perfect identity of effects, can only arise from an identity of causes.

These discoveries are, like the genius of their author, universal; but before we proceed any farther, it will be proper to enquire a little into the nature of gravitation in general, that powerful agent, which produces so many astonishing effects. It has been shown, that by the action of this invisible power, a stone is made to fall to the ground, the moon circulates about the earth, and the satellites of Jupiter and Saturn round the bodies of those planets. The Newtonian doctrine, which proves the truth of these laws from mathematical principles, is called the System of Universal Gravitation, or Attraction. But what is this occult principle of sympathy and union, which gives life and motion to inanimate beings, and how does it act? The effects are visible, but the agent that produces them is hid from our senses. It eluded the search of Newton himself; he that soared to the utmost regions of space, and looked through nature with the eye of an eagle, was unable to discover it.

That there is, however, such a principle, is not to be doubted. To deny its existence, would be to deny the truth of facts, established both by experiment and demonstration. That two distant bodies will approach towards each other, without any visible agent either drawing or impelling them, may be made manifest by various instances. The loadstone and a piece of iron mutually attract each other; two cork balls, swimming in water, approach together and meet; and, in electricity, we have numberless experiments to show, that several other bodies have a like tendency to unite and adhere to each other. These bodies, it is true, act by particular laws, different from that of gravity; but they serve sufficiently well to illustrate the nature of that principle.

But lest these instances should be thought insufficient, it may not be amiss to mention another, which, independently of mathematical demonstrations, goes near to show the universality of this property.

The French mathematicians who were employed in measuring the circumference of the earth, observed that a large mountain in South America had a sensible effect upon the plumb line of their instruments: but as this was a business foreign to that in which they were engaged, they neglected to make the observations which were necessary to establish its validity. The Royal Society, however, from this and other considerations, were induced to prosecute the enquiry. And Dr. Maskelyne, the late astronomer-royal, who was employed by them for this purpose, has furnished us with a series of observations, made on the mountain Schehallien in Scotland, from which it appears that, by the force of its attraction, the plumb line was drawn out of its vertical direction about six seconds of a degree.

This instance is sufficient to show that all bodies whatever attract and are attracted; and it has been farther proved, by Newton, that their mutual actions upon each other, are in exact proportion to the quantity of matter they contain. As the sun, therefore, is the largest body in our system, he may be considered as the emperor of the world, and the earth, planets, and comets, as his subjects: by virtue of his power they move round him in their several orbits, "and from his lordly eye keep distance due, aloof amid the vulgar constellations thick." Among the planets, also, there are several orders of nobility. The Earth, Jupiter, Saturn, and Uranus, are the sovereigns of their dominions, and have the satellites or moons for their attendants. They each move round their master, in obedience to his will, and are subject to the laws he imposes on them. Thus celestial and sublunary nature are the same; order and regularity result from seeming confusion, and subordination and dependence are to be seen in every part of the universe.

This illustrious philosopher had made his discoveries in geometry, and laid the foundation of his two celebrated performances, the Principia and the Treatise on Optics, when he was only twenty-four years of age; which is a circumstance no less extraordinary than the discoveries themselves; and serves to countenance the idea of Fontenelle, who observes, upon this occasion, that if intelligent beings, of an order superior to man, make a progress in knowledge by certain gradations, they probably fly whilst we creep, and pass over, without notice, many of the intermediate steps, which the confined limits of the human mind render absolutely necessary to our advancement.

" When we consider, says this ingenious writer, that, according to the doctrine of Newton, every single satellite of Saturn must gravitate towards the other six; the other six towards the seventh; all the seven towards Saturn; and Saturn and all of them towards the sun, according to a particular law: what an immense skill in geometry must have been requisite to unravel the intricacies of so many different relations. It was a daring attempt to undertake it; and one cannot perceive, without amazement, that from so abstracted a theory, formed of so many particular theories, and each of them perplexed with innumerable difficulties, conclusions should always arise exactly conformable to fact and experience." These are, certainly, such instances of genius and penetration, that, when taken in their fullest extent, the idea of the poet will scarcely be thought too extravagant:

"Nature and Nature's laws lay hid in night,
God said, Let Newton be, and all was light."

POPE.

LETTER VIII.

OF THE NATURE OF THE TIDES.

In my last letter I have unfolded to you the grand principle of attraction, and the manner in which it operates. We have seen the genius of Newton in the heavens, and travelled with him to the sun and the planets. Let us now descend, and follow him into the world of waters, through the depths of the ocean. By what power or cause is it, that this vast liquid body rises and falls alternately, twice a day, in a manner so constant and regular. The ancients considered it as one of the greatest mysteries in nature, and were utterly at a loss to account for it.

Aristotle, the great oracle of antiquity, is represented as having thrown himself into the sea, because he was unable to explain its motions; and when he was in India, with Alexander the Great, it is said that he wanted to follow the tide in its reflux, to see where it would go. The story is sufficiently absurd; but not more so than the following one related of Kepler. He, in one of his reveries, considered the earth as a living being, and thought the flux and reflux of the sea was the effect of its respiration: men, and other creatures, he conceived to be insects which feed upon this animal; bushes and trees the bristles on his back; and the water of seas and rivers a liquid which circulates in his veins.

Galileo, Des Cartes, and even Kepler, have, however, expressed themselves more philosophically upon this subject; but the first who clearly pointed out the cause of the phænomenon, and showed its agreement with the effects, was Newton. To a genius like his, enterprise and discovery were recreation. The moon he presently saw was the principal agent which produces these motions; and, by applying his new principles of geometry and attraction to the enquiry, he soon showed the manner in which they are effected. To follow him through all his calculations, would be to perplex the subject instead of elucidating it. Not to insist, therefore, upon abstruse investigations, which are intelligible only to mathematicians and philosophers, I shall begin by describing the most obvious facts, and afterwards show their conformity with the theory he has established.

The ocean, it is well known, covers more than one half of the globe; and this large body of water is found to be in continual motion, ebbing and flowing alternately, without the least intermission. What connection these motions have with the moon, we shall see as we proceed; but, at present, it will be sufficient to observe that they always follow a certain general rule. For instance, if the tide be now at high-water-mark, in any port, or harbour, which lies open to the ocean, it will presently subside, and flow regularly back, for about six hours, when it will be found at low-water-mark. After this, it will again gradually advance for six hours, and then return back, in the same time, to its former situation; rising and falling alternately, twice a day, or in the space of about twenty-four hours.

The interval between its flux and reflux, is, however, not precisely six hours, but about eleven minutes more; so that the time of high water does not always happen at the same hour, but is about three quarters of an hour later every day, for thirty days, when it again recurs as before. For example, if it be high water to-day at noon, it will be low water at eleven minutes after six in the evening; and, consequently, after two changes more, the time of high water the next day, will be at about three quarters of an hour after noon; the day following it will be at about half an hour after one; the day after that at a quarter past two; and so on for thirty days; when it will again be found to be high water at noon, the same as on the day the observation was first made: which exactly answers to the motion of the moon; she rises every day about three quarters of an hour later than upon the preceding one; and, by moving in this manner round the earth, completes her revolution in about thirty days, and then begins to rise again at the same time as before.

To make the matter still plainer; suppose, at a certain place, it is high water at three o'clock in the afternoon, upon the day of the new moon; the following day it will be high water at three quarters of an hour after three; the day after that at half an hour past four; and so on, till the next new moon; when it will again be high water exactly at three o'clock, the same as before. And by observing the tides continually, at the same place, they will always be found to follow the same rule: the time of high water, upon the day of every new moon, being exactly at the same hour; and three quarters of an hour later every succeeding day.

Such a perfect harmony of motions, as is here pointed out, could not possibly arise from the mere concurrence of fortuitous causes, or the uncertain operations of blind chance, as many sceptical philosophers affect to believe. On the contrary, they are in such exact conformity with the motion of the moon, that, independently of all mathematical considerations, we should certainly be induced to look to her as their cause. Neglecting, therefore, for the present, all such exceptions as do not affect the truth of the theory, we will proceed to show, from principles laid down by Newton, that these phænomena are principally occasioned by the moon's attraction.

For this purpose it will be proper to observe, that the earth and moon mutually attract each other; in consequence of which they would approach towards the same point, if it were not for a contrary force acting in an opposite direction; which being such as to cause an equilibrium of the two, their mean distance is preserved. The latter of these is called the centrifugal force, being that by which revolving bodies have a tendency to recede from their centres of motion; as a stone, when whirled round in a sling, has a tendency to fly off, and which requires a greater or less force to counteract it, according to the velocity with which it revolves. And as the earth and moon may be considered as revolving about their common centre of gravity, it is obvious, that they will have a mutual tendency to recede from each other, or from their common centre of gravity.

Now this force by which the earth is prevented from approaching towards the moon, acts equally on all its particles; since each of them, moving with the same velocity, has the same tendency to recede. But the force by which they have a tendency to approach, is not equal in every particle; it being a law of attraction, that the force increases as the squares of the distances decrease. Whence it is obvious, that the surface of the earth, or ocean, nearest the moon, is attracted by a greater force than the centre; and therefore the waters will have a tendency to rise in those parts immediately under the attracting body.

In order to illustrate this by a figure, let M (Pl. III. fig. 6.) represent the moon, O the centre of the earth, and Z, R, N, &c. different points upon its surface; and for the sake of perspicuity, let us suppose the earth to be entirely covered by the ocean. Then the moon M will act upon the surface of the sea at the points Z, R, N, &c. as well as upon the centre O. But the point Z being nearer to the moon than the point O, the attraction at Z will be greater than at O; and at any other intermediate points, the attractive force will be different, according to their different distances from the moon.

Now as every particle has an equal tendency to recede from the moon, but an unequal one to approach towards it; and since this latter attractive force is greatest on the part of the ocean, which lies immediately under the moon, the waters will, of course, flow constantly to that part, and be elevated or depressed at different places, according as her situation changes with respect to those places. But as the earth turns round on its axis, from the moon to the moon again, in about twenty-four hours and three quarters, the flux and reflux will be necessarily retarded, from day to day, about three quarters of an hour, which is agreeable to experience, and what we have before mentioned.

So far then it must appear perfectly clear, that the tides are occasioned by the attractive power of the moon: but a circumstance the most singular, and difficult to conceive, remains yet to be explained: which is, that they ebb and flow twice a day, or in the space of about twenty-four hours. When the moon passes the meridian, or is at her greatest height above the horizon of any place, she will evidently attract and elevate the waters which lie immediately under her: but what is the reason, that twelve hours afterwards, when she passes the meridian below the horizon, the waters, at the same place, are then also elevated? We know from experience, that, whether the moon be in the zenith or nadir, the phænomenon is nearly the same; it being high water with us at the same time that it is high water with our antipodes.

This circumstance seemed, at first, so opposite to the nature of attraction, that some philosophers, who did not examine it with proper attention, thought it a sufficient refutation of that doctrine. But the edifice of Newton is built upon a rock, and is not to be shaken by every idle wind that blows. It was ingenuously observed, upon a similar occasion, by his polite and candid opponent, the accomplished Marquis de Polignac, that what this great man asserts to be a fact must not be hastily rejected; and I shall now show you the necessity of attending to this precaution, in the instance before us.

Let M (Pl. III. fig. 6.) represent the moon as before; O the centre of the earth; and Z and N those parts of the surface which are the nearest to the moon, and the farthest from her; and, for the sake of perspicuity, let us suppose the earth, in this instance also, to be entirely covered by the ocean. Then as we have before seen, the waters at the point Z, nearest the moon, will be elevated, because this point is more strongly attracted by the moon than the centre O; and because N is more remote than the centre O, the attractive power of the moon M, will be less at N than at O. Whence, since every particle has an equal tendency to recede from the moon, but an unequal one to approach towards it, it follows, that those parts which are the least attracted will recede the farthest; that is, the waters at N, will recede the farthest from M, and consequently be equally elevated at this point, as at Z. So that the attractive force of the moon will evidently raise the waters, both at that point of the surface which is nearest to her, and at that which is farthest from her, at the same time, as was to be shown.

Following this system, then, it is to be observed, that at any port or harbour which lies open to the ocean, the action of the moon will tend to elevate the waters there, when she is on the meridian of that place, whether it be above the horizon or below it. But the water cannot be raised at one place, without flowing from, and being depressed at another; and these elevations and depressions will obviously be the greatest at opposite points of the earth's surface. When the moon raises the waters at Z and N, they will be depressed at H and R; and when they are raised by her at H and R, they will be depressed at Z and N. And as the moon passes over the meridian, and is in the horizon, twice every day, there will therefore be two tides of flood and two of ebb in that time, at the interval of about six hours and eleven minutes each; which is exactly conformably to theory and experience.

One great privilege of genius seems to be, that of considering difficult things under a point of view which renders them more simple and perspicuous, and enables the mind to comprehend and follow them with ease and facility. This felicity of conception was possessed by Newton in the highest degree: he always knew, in every case which required investigation, the proper mode of resolving the question. Geometry and mechanics were his favourite sciences, and, by their means, he soon conquered every difficulty. We have seen, in the present instance, how easily he removed objections, and reconciled apparent contradictions. The occuring of the tides at the same place twice a day, was made use of as an argument against the truth of his grand principle of attraction; but this, so far from being repugnant to that doctrine, he has shown to be a necessary consequence of it.

Another seeming objection may also be removed with the same ease. From a slight consideration of what has been said, you might be led to imagine, that the time of high water at any place, would be when the moon is over the meridian of that place. But this is by no means the case: it is usually about three hours afterwards; the reason of which may be shown as follows. The moon, when she is on the meridian, or nearest to the zenith of any place, tends to raise the waters at that place; but this force must evidently be exerted for a considerable time, before the greatest elevation will take place; for if the moon's attraction were to cease altogether, when she has passed the meridian, yet the motion already communicated to the waters would make them continue to ascend for some time afterwards; and, therefore, they must be much more disposed to ascend, when the attractive force is only in a small measure diminished.

The waves of the sea, which continue after a storm has ceased, and almost every other motion of a fluid, will illustrate this idea; all such effects being easily explained, from the consideration that a small impulse, given to a body in motion, will make it move farther than it would otherwise have done. It is also, upon the same principle, that the heat is not the greatest upon the longest day, but some time afterwards; and that it is not so hot at twelve o'clock, as at two or three in the afternoon; because there is a farther increase made to the heat already imparted. Instead of its being high water, therefore, when the moon is upon the meridian of any place, it will always be found to happen, as far as circumstances will allow, at about three hours afterwards; and the intervals between the flux and reflux, must be reckoned from that time in the same manner as before.

From what has been hitherto said, it may be supposed that the moon is the sole agent concerned in producing the tides. But it will be necessary to observe, before we quit the subject, that the influence of the sun would also produce a similar effect, though in a much less degree, than, from his superior magnitude, we should naturally be led to imagine. For it is not the entire actions of those bodies upon the whole globe of the earth, that is here to be considered, but only the inequalities of those actions upon different parts of it. The whole attractive force of the sun is far superior to that of the moon; but as his distance from the earth is near four hundred times greater, the forces with which he acts upon different parts of it, will approach much nearer to equality than those of the moon; and consequently will have a less effect in producing any change of its figure. For, from what has been observed, it is manifest that if all the parts of the earth were equally attracted, they would suffer no change in their mutual situations.

That this doctrine may be still more clearly understood, let it be considered, that though the earth's diameter bears a considerable proportion to the distance of the earth from the moon, yet this diameter is almost nothing when compared to the distance of the earth from the sun. The difference of the sun's attraction, therefore, on the sides of the earth under and opposite to him, will be much less than the difference of the moon's attraction on the sides of the earth under and opposite to her: for which reason, the moon must raise the tides much higher than they can be raised by the sun. Newton has calculated the effect of the sun's influence, in this case, and found that it is about one third of that of the moon. The action of the sun alone would, therefore, be sufficient to produce a flux and reflux of the sea; but the elevations and depressions occasioned by this means, would be about three times less than those produced by the moon.

The tides, then, are not the sole production of the moon, but of the joint forces of the sun and moon together. Or, properly speaking, there are two tides, a solar one, and a lunar one, which have a joint or opposite effect, according to the situation of the bodies that produce them. When the actions of the sun and moon conspire together, as at the time of new and full moon, the flux and reflux becomes more considerable; and these are then called the Spring Tides. But when one tends to elevate the waters, whilst the other depresses them, as at the moon's first and third quarters, the effect will be exactly the contrary; the flux and reflux, instead of being augmented, as before, will now be diminished; and these are called the Neap Tides.

But as this is a matter of some importance, it may be worth while to enter into a more minute explanation of it. For this purpose, let S (Pl. III. fig. 7.) represent the sun, ZHNR the earth, and F and C the moon at her full and change. Then, because the sun S, and the new moon C, are nearly in the same right line with the centre of the earth O, their actions will conspire together, and raise the water about the zenith Z, or the point immediately under them, to a greater height, than if only one of these forces acted alone. But it has been shown, that when the ocean is elevated at the zenith Z, it is also elevated at the opposite point, or nadir N, at the same time; and, therefore, in this situation of the sun and moon, the tides will be augmented. Again, whilst the full moon F raises the waters at N and Z, directly under and opposite to her, the sun S, acting in the same right line, will also raise the waters at the same points Z and N, directly under and opposite to him; and therefore, in this situation also, the tides will be augmented; their joint effect being nearly the same at the change as at the full; and, in both cases, they occasion what are called the Spring Tides.

Pursuing the illustration in the same way, let now F and T (Pl. III. fig. 8.) be the moon in her first and third quarters, and the rest as before. Then, since the sun and moon act in the right lines S O and FT, which are nearly perpendicular to each other, their forces will tend to produce contrary effects; because the one raises the waters in that part, where the other depresses them. The sun's attraction at R and H, will diminish the effect of the moon's attraction at Z and N; so that the waters will rise a little at the points under and opposite to the sun, and fall as much at the points under and opposite to the moon; and of course the lunar tides will be diminished in those parts. This respects the moon only in her first quarter, at F; but the same reasoning will evidently hold, when applied to the moon in her third quarter, at T; for as the sun and moon still act in lines which are perpendicular to each other, they must produce the same diminution as before; and in both these cases they occasion what are called the Neap Tides. But it must be observed, that neither the Spring nor Neap Tides happen, when the sun and moon have the precise situations here mentioned; because, in this case, as in all others, their actions do not produce the greatest effect when they are the strongest, but some time afterwards.

The effects of the disturbing forces of the sun and moon, depend, likewise, upon their respective distances from the earth, as well as upon their particular situations. For the less the distances are, the greater will be the effects; and, therefore, in winter, when the sun is nearer to the earth, the spring tides will be greater than in summer, when he is farther off; and the neap tides, on that account, will be less. And, for a like reason, as the moon moves in an elliptical orbit round the earth, and is nearer to us at some times than at others, the tides will, at those times, be greater, and at the opposite points of her orbit less. Some variations, likewise, take place in consequence of the different declinations of the sun and moon at different times. For if either of these luminaries were at the pole, it would occasion a constant elevation both there and at the opposite one, and a constant depression at the equator; so that as the sun and moon gradually decline from the equator, they lose their effect, and the tides become less; and when they are both in the equator, the tides of course become greater.

These are the principal phænomena of the tides; and where no local circumstances interfere, the theory and facts will be found to agree. But it must be observed, that what has been here said, relates only to such places as lie open to large oceans. In seas and channels, which are more confined, a number of causes concur, which occasion considerable deviations from the general rule. Thus, it is high water at Plymouth about the sixth hour; at the Isle of Wight about the ninth hour; and at London-bridge about the fifteenth hour, after the moon has passed the meridian. And at Batsha, in the kingdom of Tonquin, the sea ebbs and flows but once a day; the time of high water being at the setting of the moon, and the time of low water at her rising. There are, also, great variations in the height of the tides, according to the situation of coasts, or the nature of the streights which they have to pass through. Thus, the Mediterranean and Baltic seas have very small elevations; while, at the port of Bristol, the height is sometimes forty feet; and at St. Malo's it is said to be near a hundred.

What has been said of the ocean may likewise be applied to the air; for the surface of the atmosphere being nearer to the moon than the surface of the sea, it is plain that the aerial tides must be much more considerable than those of the ocean: and on this account it should seem to follow, that the mercury in the barometer would sink considerably lower than at other times, when the moon passes the meridian; because her action on the particles of air, must, at that time, make them much lighter. But it must be considered, that in proportion as these particles are rendered lighter, a greater number of them are accumulated, till the deficiency of gravity is made up by the height of the column; and as there is then an equilibrium, the pressure will evidently be the same as before; and consequently the mercury in the barometer, cannot, in any respect, be affected, by means of these tides.

LETTER IX.

OF THE LATITUDE AND LONGITUDE, AND THE METHODS OF DISCOVERING THEM.

In almost all difficulties we have our resources; and such are the inventive powers of the mind, that there are but few things, which it is useful for us to know, but what some means have been devised for obtaining a knowledge of them. To determine the true place of a ship at sea, is a problem, which was formerly placed in the same degree of probability with the secret of prolonging life, the perpetual motion, the squaring of the circle, and other similar projects: but, impossible as the solution of it might appear, it can now be obtained to a degree of precision, sufficient to answer most practical purposes. By the help of a few books, and a quadrant, the mariner can not only inform himself of the situation he is in, but also how far he has travelled, what distance he has to go, and how he must direct his course to arrive at the place he designs to visit.

In this enquiry, nothing more is necessary, than to find the latitude and longitude of the places under consideration; for these being once known, by only turning to a common map or globe, the places themselves will be found by inspection. What is to be understood by these terms, and how they are applicable to the purposes mentioned, you will, no doubt, be anxious to enquire; and I shall endeavour to satisfy your curiosity to the utmost of my power. The subject is no less useful than curious, being the very foundation both of geography and navigation; and, in order that you may obtain as clear an idea of it as possible, we will begin with the first principles, and proceed gradually, step by step, to their application.

In the first place, then, as it is absolutely necessary for you to have a perfect conception of what is meant by the poles of the earth, the equator, and the meridians, I shall describe them in as familiar a manner as the subject will admit, and at the same time show you their use and design. The poles are the two extremities of the earth's axis; or those points where the imaginary line, round which it performs its daily revolutions, meets the earth's surface: that which is directed towards the most northern point of the heavens, being called the north pole; and that which is directed towards the most southern point, the south pole. So that they are diametrically opposite to each other, and always preserve the same relative situation.

"Two poles turn round the globe, one seen to rise
O'er Scythian hills, and one in Libyan skies;
The first sublime in heav'n, the last is hurl'd
Below the regions of the nether world;
Where, as they say, perpetual night is found,
In silence brooding on the unhappy ground:
Or, when Aurora leaves our northern sphere,
She lights the downward heav'n, and rises there;
And when on us she breathes the living light,
Red Vesper kindles there the tapers of the night."

VIRGIL.

It is, also, to be observed, that these two points have not been arbitrarily assumed by geographers and astronomers, to answer their particular purposes, for they are pointed out to us by the nature and constitution of the globe, and are easily distinguished from all others. The nearer we approach to them, the more we find the earth becomes barren and inhospitable; so that, under the poles, the cold is so excessive, that the country is, in all probability, wholly uninhabitable. Many attempts have been made to explore these remote regions, but they have all hitherto failed; and there is great reason to imagine that they are utterly inaccessible (*f*). The immense quantities of ice with which the ocean, in those parts, is continually covered, renders navigation impracticable; and any method of approaching them by land, would be subject to still greater impediments.

From these considerations, you will be able to obtain a precise and determinate idea of the poles. Imagine now a circle to be drawn round the globe, exactly in the middle between these two points, and this will be the equator; which, properly speaking, is a great circle of the earth, that separates the northern from the southern hemisphere, and is every where at an equal distance from the two poles. This circle is also no less remarkable, on account of its situation, than the poles themselves; the heat here being almost as intense as the cold is there; for which reason, the ancients imagined the

(*f*) The nearest approach towards the north pole was that made by Captain Phipps, in the year 1773, when he penetrated as far as latitude eighty degrees thirty-seven minutes; where the sea was entirely blocked up with ice.

countries in both situations to be equally uninhabitable. Since the globe, however, has been farther explored, it has been found that many places, which lie directly under the equator, are extremely populous, notwithstanding the excessive heat of the climate; and even the bleak regions of the pole are not wholly desolate; so that the following description of those parts must be considered as more poetical than just.

> "The fields of liquid air, inclosing all,
> Surround the compass of this earthly ball:
> And as five zones th' etherial regions bind,
> Five, correspondent, are to earth assign'd:
> The sun, with rays directly darting down,
> Fires all beneath, and fries the middle zone:
> The two beneath the distant poles complain
> Of endless winter, and perpetual rain:
> Betwixt th' extremes, two happier climates hold
> The temper that partakes of hot and cold."
>
> OVID.

Having fixed the position of the poles and equator, it will be easy to form a notion of any other circles that can be drawn upon the globe. A meridian, for instance, is a certain great circle, which is supposed to pass through the two poles, and to divide the eastern half of the earth from the western half. And because any place, which lies to the east or west of another, may have a circle of this kind drawn through it, you will readily perceive that there may be as many meridians as there are places of different situations. The meridian of any particular place is also to be known, by its being that circle in which the sun is always to be found at noon, or when he is at an equal distance both from the point where he rises, and that where he sets.

But what has been here described, will perhaps be better understood from the following figure, (Pl. III. fig. 2.) where the line SN represents the axis of the earth, or that line about which its diurnal revolution is performed, N and S, the north and south poles, and EQ, the equator; also SAN, SBN, SCN, &c. are meridians passing through the north and south poles, and each dividing the earth into an eastern and western hemisphere, the same as the equator EQ, divides it into a northern and southern hemisphere.(*g*)

These are the principal circles concerned in the present subject; and if they be properly understood, what follows will be found perfectly easy. The equator, for instance, is represented as a boundary, which separates the northern from the southern hemisphere; and the latitude of a place is its distance north or south from this circle. If the place lies in the northern hemisphere, it is said to have north latitude; and if it lies in the southern hemisphere, it is said to have south latitude: so that the latitude of any place will be greater or less, according as it is farther from, or nearer to the equator. And in order to estimate this distance, we conceive a meridian to be drawn through

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(*g*) A description of the various circles of the sphere, will be found in the explanation of the principal terms made use of in astronomy, given at the end of the work.

the place proposed; and by reckoning how many degrees of that circle are contained between this point and the equator, we are enabled to judge of the situation of the place with respect to its latitude.

Every circle is supposed to be divided into 360 equal parts, called degrees, and every degree into sixty equal parts, called minutes; so that, from these considerations, you will readily perceive what is to be understood by the latitude being expressed in degrees and minutes, and how the distance of any place from the equator may be assigned by them. If, for example, a place is said to have ninety degrees of north latitude, it must, evidently, lie under the north pole; and if it has ninety degrees of south latitude, it must be under the south pole. In like manner, any place which is exactly in the mid-way between the equator and either of the poles, will have forty-five degrees of latitude, north or south, according to the hemisphere in which it lies: so that under the equator the latitude is nothing, but increases gradually as you advance towards either of the poles, where it is ninety degrees, or the greatest possible; as will be evident from consulting the above-mentioned figure.

A great number of different places it is obvious, may also have the same latitude; for if a circle be supposed to be drawn through any point of the meridian, parallel to the equator, all the places which lie under that parallel will be equally distant from the equator, and consequently must have the same latitude; as is the case of the circles 10, 10; 20, 20; &c. It appears, therefore, that by knowing the latitude of a place only, we are not from this alone able to ascertain its exact situation. We can tell under what parallel it lies, or what is its distance from the equator; but other considerations are necessary to fix its precise position in that parallel, and to enable us to find it upon a map or globe.

Before we can do this, we must know the distance of the place from a certain meridian, as well as its distance from the equator. But as none of these circles are, in their own nature, distinguishable from the rest, it will be necessary to fix upon some one in particular, and agree to refer all our computations to that. Suppose, for example, that we take any remarkable place upon the earth, and consider the meridian which passes over it, as the principal one: this may then be called the first meridian, and by noting the points where it cuts the equator, the distance of any place may be properly reckoned from it in degrees and minutes of that circle.

The choice of a first meridian has been a matter of considerable embarrassment both to astronomers and geographers, and even yet they are not perfectly agreed in their determinations. The French formerly made their first meridian pass through the island of Ferro, one of the Canaries; and the Dutch fixed upon another of those islands, called Teneriffe, as the properest situation for this purpose. But the English, with more propriety, make their first meridian pass over London, or rather over Greenwich, on account of the Royal Observatory being at that place. This disagreement amongst the astronomers of different nations is not, however, to be considered as a matter of much importance; for whichever is regarded as the first meridian, the rest may be easily deduced from it, by noting the different points where they intersect the equator, and finding the difference.

The idea of making the meridian pass over the capital of a kingdom is a very natural one; but you will, no doubt, be curious to know why the islands of Ferro and Teneriffe were fixed upon in preference to all other places for this purpose. The principal reason seems to have been, on account of the westerly situation of these places; for as they lie in the Atlantic ocean, between Europe and America, the first meridian being made to pass over this part of the globe, might then be considered as the western boundary of Europe: besides which, the Dutch and Germans imagine the peak of Teneriffe, on account of its being one of the highest mountains in this part of the world, to be a place peculiarly proper for this purpose.

These reasons, however, are by no means satisfactory. The true position of the Canaries was not, till very lately, determined; and it must surely be injudicious to make the first meridian pass over a place whose situation is but imperfectly known. Let us, therefore, follow our countrymen, and, without regarding the practice of other nations, refer the longitude of different places to the meridian of London. This meridian, which, in the preceding figure, is represented by the line SN, and may now be called the first, cuts the equator in two opposite points, at the distance of 180 degrees each way; and as the equator is the boundary which separates the northern hemisphere from the southern, so this circle may be considered as the boundary which separates the eastern hemisphere from the western.

The relation between these two circles is, also, still farther observable: for as the latitude of any place is its meridional distance from the equator, so the longitude of any place is its equatorial distance from the first meridian. If the place lies in the eastern hemisphere, it is said to have east longitude; and if it lies in the western hemisphere, it is said to have west longitude; the longitude of any place being greater or less, according to its east or west distance from the first meridian. But, in order to obtain a true estimate of this distance, we must conceive a meridian to be drawn through the place proposed, and then, by reckoning how many degrees of the equator are contained between this and the first meridian, we shall be enabled to judge of the situation of the place with respect to its longitude.

This method is, however, subject to some ambiguities, which arise from considering the meridians as entire circles. Let us therefore consider them only as semicircles, drawn from one pole to the other, and all difficulties of this kind will be easily avoided. For, since the equator may now be divided into 180 degrees each way from the first meridian, and none of these semicircles can intersect it in more points than one, the method of reckoning the longitude will be perfectly clear and intelligible. If, for example, the meridian of any place cuts the equator at twenty degrees distance from the first meridian, the longitude of that place will be twenty degrees, east or west, according to its situation; and so for any other place under the same meridian. Thus all places under the meridian CN have ten degrees of longitude, and those under BN, twenty degrees, and so on, for any other meridian whatever.

From this consideration it is also evident, that the greatest longitude a place can have is 180 degrees; and that the longitude of any place lying under the first meridian will be nothing. A great number of different places may also have the same longitude; for if a meridian be supposed to be drawn through any point upon the globe, all places lying under that meridian, when referred to the equator, will be at an equal distance from the first meridian, and consequently their longitude must be the same, as I have before stated. It appears, therefore, that by knowing the longitude of a place only, we are not, from that circumstance alone, able to ascertain its exact situation, any more than we were from knowing the latitude only. We can tell under what meridian it lies, and what is its equatorial distance from the first meridian; but something more must be understood, before we can fix its precise position upon the globe. This knowledge is obtained, by finding both the meridian and the parallel of latitude that pass over the place under consideration; in which case, the point where these two circles intersect each other will be the true situation of the place proposed.

Thus, in order to ascertain the exact place on the earth of any point, as P, we find first, that it lies in forty degrees of north latitude; but this is not sufficient; as every place in the circle 40, 40; has also the same latitude. But if, besides this, we know that it lies under any particular degree of longitude, as for example, that of forty degrees west; then its exact position is determined, being in that point where the two circles cut each other. And in the same manner we may find the position of the point R, which lies in thirty degrees north latitude, and twenty degrees east longitude; and so on.

But it is not the situation of towns and provinces only that we are so anxious to determine: to apply these principles to the purposes of navigation, is a matter of still greater importance. In travelling by land, we are subject to few inconveniencies; but the calls of ambition, business and pleasure, have exposed men to new dangers. When the discovery of the compass invited the voyager to quit the consolatory sight of his native shore, and to venture himself upon an unknown ocean, that knowledge, which he might have thought but of little consequence before, became now a matter of absolute necessity. Floating in a frail vessel, upon an uncertain abyss, he has consigned himself to the mercy of the winds and waves, and knows not where he is: an uniform simultaneous plane, and an uninterrupted horizon, is all that he sees around him. The compass will direct him in his course, but it shows him neither the coasts he has left behind, nor those he endeavours to find.

In this situation of danger and distress, having no other resource, he applies to the heavens for assistance: the same stars, which he saw in his native country, are still visible in the firmament, and these are his only guides. Being fixed and immoveable, their situations are known; and rules have been derived from this property, which will enable him to find the latitude of the place at which he is arrived. But as many places have the same latitude, this only informs him that he is somewhere in a certain circle which is parallel to the equator. To tell exactly in what part of this circle he is, he must also find the difference of longitude, and determine the meridian which cuts the parallel in the place occupied by his vessel.

The latitude of a place is easily discovered, but the longitude is a subject of the utmost difficulty. Many methods have been devised for this purpose, which are sufficiently accurate upon land; but at sea, where precision is most wanted, they are least to be depended upon. The problem is so intimately connected with trade and commerce, that princely rewards have been offered for an easy and accurate solution of it. By an act of parliament, passed in the year 1714, the English government offered 20,000 pounds reward to any person who should discover a method for finding the longitude of places at sea, within thirty miles, or half a degree of a great circle: 15,000 pounds if it came within two-thirds of a degree, and 10,000 pounds if it came only within a degree of the truth. Such a liberal encouragement induced the learned, of all nations, to attempt this important discovery, which now became doubly interesting, both by the honour and profit which attended it.

I shall not perplex you with a long detail of all the methods invented by astronomers for this purpose, as they are frequently involved in abstruse calculations, which you would find both tedious and unintelligible. A general idea will be best obtained by considering those only, which are the most simple and easy; and if these be properly understood, it will not be difficult for you to comprehend the principles upon which they are all founded. Disregarding, therefore, all minute particulars, we will first begin with the latitude, and show the means which have been used to discover the distances of places from the equator.

In this enquiry, the first method that suggests itself, is that of finding the height of the pole. For as this point is immoveable in the heavens, and is found to be elevated or depressed according as we are farther from, or nearer to, the equator, it affords, by this means, a criterion by which we can judge of our distance from that circle. Supposing ourselves, therefore, to be in the northern hemisphere, we will take this point for our guide, and endeavour to find the latitude of the place. The star, usually called the north pole star, is not exactly in the north point of the heavens: but, for the sake of illustrating the subject, we will suppose that it is, and see what will follow from its having this situation.

Let NS, (Pl. IV. fig. 9.) therefore, be the axis of the earth, produced to the polar star P; EQ the equator, and Z the zenith, or place of observation: then, since ZO, the distance of the zenith from the horizon, is ninety degrees; and NE, the distance of the pole from the equator, is also ninety degrees; the arc OZ will consequently be equal to the arc NE; and if the arc NZ, which is common to them both, be taken away, the remainder ON, will be equal to the remainder ZE: but ON is the height of the pole above the horizon, and ZE is the latitude of the place, or its distance from the equator; and therefore, if the height of the pole above the horizon be taken by means of a quadrant, or any other instrument proper for the purpose, it will evidently give the latitude of the place where the observation was made. Thus, the height of the north pole at London is found to be about fifty-one degrees, thirty-two minutes; and therefore this is the latitude of the place, or its distance north from the equator.(*h*)

(*h*) The only thing that can stand in need of farther illustration on this head is, that it may not appear, at first sight, how a person standing on the surface of the earth at Z, can measure the angle NCO at the centre, or the altitude of the polar star ON; but this seeming difficulty vanishes, when we consider the immense distance of the fixed stars, to

But as the pole star is not exactly in the north point of the heavens, let some other star be taken which is about eight or nine degrees from that point; and find, with a quadrant, its greatest and least altitude, in the same manner as before. Then, as the star moves in a small circle round the pole, which it describes in about 24 hours, it is evident that, if the least of the two altitudes be added to half their difference, it will give the height of the pole, or the latitude of the place required. For, let *b* and *a* (Pl. IV. fig. 9.) be the two positions of the star at its greatest and least altitudes, and N the true north point of the world; then, since *b* and *a* are diametrically opposite to each other, and N is exactly in the middle between them, it is plain that if O *a*, the least altitude, be added to *a* N, half the difference of the altitudes, it will give ON, the height of the pole above the horizon; which, as was before shown, is equal to ZE, the latitude of the place of observation.

This method, however, is liable to some exceptions; and as the same thing may be done by taking only a single altitude of the sun or a star, when it is upon the meridian, it is usually preferred in practice to the former. The problem admits of several cases, according to the situation of the observer: but as they are all equally easy, an explanation of one of them, will be a sufficient elucida-

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which the radius of the earth is a mere point; and consequently, the angle of elevation at Z, will be the same as at C; because if a line ZP be drawn from Z to P, it will be so nearly parallel to CP, as to occasion no sensible error.

tion of the whole. Suppose then, a spectator at Z (Pl. IV. fig. 10) to observe the sun, at noon, over the point S, and to find, with a quadrant, his meridian altitude HS; then, if this altitude be taken from HZ, or ninety degrees, it will give the zenith distance ZS; and the zenith distance ZS, being added to the declination of the sun SE, will be the latitude of the place required.(*i*)

The sun's declination, is his distance north or south from the equator; and as this may be found in the Nautical Almanac, ready computed for the noon of every day in the year, the latitude may always be easily obtained from it. Thus, for example, suppose that at some unknown place in the Western Ocean, the sun's meridian altitude was observed to be forty-four degrees fifty-one minutes, and that his declination, as found in the tables, was six degrees twenty-three minutes north; then, by taking forty-four degrees fifty-one minutes from ninety degrees, the difference, which is forty-five degrees nine minutes, is the distance of the sun from the zenith; and this being added to six degrees twenty-three minutes, the sun's declination, gives fifty-one degrees thirty-two minutes for the latitude required; which shows the place, in this instance, to be upon the same parallel with London. And if any remarkable fixed star be taken instead of the sun, the latitude may be found from

(*i*) Supposing a line to be drawn from Z to the sun, the difference between taking the elevation of the sun from the centre of the earth, or from its surface, will be insensible, for a similar reason to that mentioned in the last note.

its declination and altitude, in exactly the same manner.

These are the most popular methods of finding the latitude; and as what has been said upon them is sufficient to give you a general idea of the subject, I shall now proceed to the longitude, and endeavour to show that this may be obtained, to a certain degree of exactness, in nearly as easy a manner as the former. In departing from any place, whose situation is known, we have only to find the direction we travel in, by means of the compass, and to measure the distance passed over, by the log, which is an instrument used at sea for that purpose; and both the latitude and longitude of the place arrived at, may be determined by a map or chart as follows:

Suppose a vessel departs from a place, whose latitude is fifty-seven degrees twenty minutes north, and longitude sixteen degrees east, and that it proceeds in an east-south-east direction 100 leagues: then, in order to determine the situation of the place at which it is arrived, take a map, or plane chart, such as is represented in Pl. IV. fig. II., in which find the place L, that the ship departed from; and draw the right line LM, making the same angle with the meridian, east-south-east, as was shown by the compass; and on this line set off the distance 100 leagues from L to M, taken from the scale in the figure, and M will represent, on the chart, the situation of the place required; which appears, by inspection, to be in latitude fifty-five degrees twenty-five minutes north, and longitude about twenty-four degrees thirty minutes east.

In this example, where the distance run, for the sake of perspicuity, is taken larger than can usually happen, it is supposed that the vessel preserves an uniform course through the whole of her voyage: but the same method will hold when she varies that direction; for if a similar operation be performed at every change, and her situation be constantly found in the chart as before, her course or direction may be traced, by these means, from one place to another, till she arrives at the place proposed. This method, however, notwithstanding its being frequently used by mariners, is liable to many obvious objections: few charts are properly constructed; and, besides the errors which will necessarily arise in estimating the course and distance, tempests and unknown currents in the ocean, may occasion such irregularities as will render it utterly impossible to ascertain the situation of the vessel with any degree of precision. So that, before any estimation of this kind can be depended upon, it must be corrected, from time to time, by astronomical observations.

This method of sailing by the stars, as it is frequently called, may be traced back as far as the time of Homer, and was probably used at a still earlier period; but from the account which he has given us, of the departure of Ulysses from the island of Calypso, it has been inferred, that his knowledge of astronomy must have been very imperfect, since he describes the constellation of the great Bear as never setting, which is only the case in certain latitudes.

"Plac'd at the helm he sat, and mark'd the skies,
Nor clos'd in sleep his ever watchful eyes.
There view'd the Pleiads, and the Northern team,
And great Orion's more refulgent beam,
To which, around the axle of the sky,
The Bear revolving, points his golden eye;
Who shines exalted on th' etherial plain,
Nor bathes his blazing forehead in the main."

ODYSSEY, B. V.

LETTER X.

THE SAME SUBJECT CONTINUED.

Another method for finding the longitude of places, is by means of a chronometer, or an instrument for measuring time. This excellent machine, so useful in the common affairs of life, is capable of affording us information upon subjects which seem to have little or no connection with it; but genius and industry find analogies where vulgar apprehension is blind. If a watch or clock could be so constructed, as to measure time with accuracy and precision, at all seasons, and in all places, such an instrument might be used to discover the longitude with the greatest ease and facility.

To illustrate this subject, we must consider the manner in which time is estimated. When the sun, in his apparent daily course round the earth, comes over any particular meridian, it is then twelve o'clock, or noon, at all places which lie under that meridian; but at all other places, it is either before noon, or after noon, according to their situation. The sun, moving from east to west, must pass over the meridian NBS before he comes to the meridian NAS (Pl. IV. fig. 12.); and consequently, when it is noon to the inhabitants who live under the meridian NBS, it will be some time before noon to the inhabitants who live under the meridian NAS. And, on the contrary, when it is noon at those places which are situated under the meridian

NAS, it will be some time after noon to the places which are situated under the meridian NBS.

But as the sun appears to move uniformly round the earth, and to describe a circle, which contains 360 degrees, in twenty-four hours, he will of course move through an arc of fifteen degrees in an hour. When it is noon, therefore, at London, and at all other places which lie under the same meridian, it will be one o'clock in the afternoon at those places which lie under the meridian fifteen degrees to the east of that of London; and eleven o'clock in the morning, at all those places which lie under the meridian fifteen degrees to the west of that of London. If the distance of the meridians be thirty degrees, it will make two hours difference in the time; if forty-five degrees, three hours; and so on, reckoning according to the situation of the places.

To make this matter still plainer, let us consider the situation of any two particular places; for instance, that of London and Paris. The meridian of Paris is two degrees twenty minutes east of the meridian of London; and this difference, reckoning after the rate of fifteen degrees to an hour, is nine minutes and twenty seconds of time. When it is noon at London, therefore, it will be nine minutes and twenty seconds after noon at Paris; and on the contrary, when it is twelve o'clock at Paris, it will be only fifty minutes and forty seconds after eleven at London: so that the clocks at London, ought to be slower than those at Paris by nine minutes and twenty seconds. In like manner, the meridian of New York, in North America, being seventy-four degrees nine minutes and forty-five seconds west of that of London, the difference of time at those places will be four hours fifty-six minutes and thirty-nine seconds; so that when it is noon at London, it is only three minutes and twenty-one seconds after seven o'clock in the morning at New York.

From these circumstances you will readily observe, that as places differ in longitude, or are situated under different meridians, so the clocks and watches of those places, supposing them to be well regulated, will show different hours at the same moment of absolute time; a difference of fifteen degrees in longitude, always producing a difference of an hour in the time shown by those machines. Knowing, therefore, the difference of time between two clocks, or watches, well regulated, at different places, it will be easy to find the difference of longitude of those places, by reckoning after the rate of fifteen degrees for every hour, and a quarter of a degree for every minute.

The difference of time shown by the clocks and watches of different places, will not appear in the least surprising, when you consider, that whilst it is noon with us, there are countries towards the east, where the sun is just setting; and others towards the west, where he is just rising; so that it is evening with the one, and morning with the other, at the same instant of absolute time that it is mid-day with us. With our antipodes, or those who live directly opposite to us upon the globe, the difference is still greater: it is noon with us, when it is midnight with them, and noon with them when it is midnight with us; their time, as well as their situation, being always directly opposite to ours. These considerations will clear the subject from al- ambiguity, and you will now be able to perceive in what way a clock or watch may be used to discover the longitude.

Suppose I had a watch of such excellent workmanship, that, being once regulated for that purpose, it would always show me, in whatever part of the world I might be, the exact time which it was then at London; by means of such a watch, I should be presently enabled to tell the longitude of the place I was in. For this purpose, I have only to find when the sun comes to the meridian of the place, or, which is the same thing, when he is exactly south; and as I then know it to be twelve o'clock at that place, the time thus found, being compared with the time shown by my watch, and the difference, turned into degrees and minutes, will give the longitude of the place required.

To illustrate this by an example; suppose I was at Petersburg in Russia, and wanted to find the longitude of that city from London. Not choosing to trust to the common account of time, as it is shown by the clocks and watches at Petersburg, I find when the sun comes to the meridian, and know it to be then exactly twelve o'clock at that place. At this moment I look at my watch, and find that, instead of its being twelve o'clock by that, it is only nine hours fifty-eight minutes and forty-three seconds. From this I conclude that, when it is noon at Petersburg, it is before noon at London, and that the difference is two hours one minute and seventeen seconds; which, by allowing fifteen degrees to an hour, answers to thirty degrees nineteen minutes and fifteen seconds. Since, therefore, the longitude of every place is supposed to be reckoned from London, and the noon at Petersburg is found to arrive sooner than the noon at London, I know the longitude of that city to be thirty degrees nineteen minutes and fifteen seconds east of London.

Instead of being in a place whose situation is known, suppose I was upon the ocean, near the coast of some country whose name I wanted to discover, I determine the moment when it is noon, in the same manner as before, and looking at my watch, I find it to be five hours seven minutes and two seconds in the afternoon, at London; from which I conclude, by allowing fifteen degrees to an hour, that I am in a place whose longitude is seventy-six degrees forty-five minutes and a half west of London. By this means I know precisely the meridian I am under; but I am yet uncertain what particular part of that meridian it is. To discover this, I find, by observing the height of the sun at noon, that the latitude of the place is eighteen degrees north of the equator; and by looking into a map or chart, I find that the place, having this latitude and longitude, is Port Royal in Jamaica, which is therefore the coast upon which I am arrived.

In this easy manner the longitude of all other places might be discovered, provided the timekeeper, or watch, was subject to no irregularities, but always showed the time exactly as it would be found at London, at the instant of observation. This kind of accuracy, however, is what we cannot reasonably hope to obtain; since every mechanical instrument, to what degree of perfection soever it may be brought, must be subject to injuries from various causes. The irregular motions of a ship at sea, and the different temperature of the atmosphere in different climates, must, in particular, affect it considerably, and occasion errors which seem to admit of no adequate remedy.

It must be observed, however, that a great deal more has been done in this way than could possibly have been expected. That excellent artist, Mr. John Harrison, considered the subject with an indefatigable and unwearied attention; and his inventions for removing the imperfections to which clock-work in general is liable, appeared to the commissioners of longitude so deserving of encouragement, that they allowed him several considerable gratuities, to enable him to bring his ideas to perfection. From a trial of his watch, made in the years 1761 and 1762, in a voyage to Jamaica, it was found to have erred only one minute and fifty-four seconds in about five months; and in another voyage to Barbadoes, the mean daily error was about two seconds and a half; for which discovery, as it came within the meaning of the act, the commissioners ordered him the sum of 10,000*l.* And some time afterwards, in consequence of his explaining the principles of his time-keepers, in such a manner as to enable others to make them with the same accuracy, he received the remaining moiety of the parliamentary reward.

Whilst Mr. Harrison was prosecuting this subject in England, Messrs Le Roy, Berthoud, &c. were engaged in the same pursuit in France; and several time-pieces were accordingly executed by them, which were found to merit the highest commendations. Messrs. Arnold, Kendall, Mudge Ernshaw, and other eminent English artists, have also made great improvements in this useful art; and furnished a number of excellent chronometers, which are now held in universal esteem. By a new act, however, which was made in the year 1774, the greatest reward which can now be obtained for the discovery of the longitude, either by this, or any other method, is 10,000*l.* and all time-pieces, which are offered for this purpose, in future, are enjoined a more rigorous trial.

If a watch, or time-keeper, like those abovementioned, cannot be procured, we have another method for finding the longitude of places, afforded us by eclipses of the moon. For since the moon has no light but what she receives from the sun, and the earth at those times is interposed between them, she must, of course, be deprived of that light, and become obscure. And as this obscurity is always real, arising from her being an opaque body, it is plain that the phænomenon may be seen from every part of the earth, where the moon is above the horizon of the place at the time the eclipse happens. This, therefore, is precisely the thing wanted; since any appearance that can be observed at two distant places, at the same moment of absolute time, will enable us to compare the time as it is reckoned at those places, and, by that means, to find the meridians under which they are situated.

The moment when the moon begins to be obscured, by entering into the earth's shadow, is called the beginning of the eclipse; and the moment when she leaves the shadow, the end. Hence if each of these be properly observed, and a mean be taken between them, this mean time is called the middle of the eclipse. The moon is sometimes entirely hid by the earth's shadow, and is then quite invisible. This is a total eclipse of the moon; and, in this case, the moment when she begins to disappear, is called the beginning of total darkness; and the moment when she begins to appear again, the end. But when only a part of the moon is obscured, the eclipse is called a partial one; and we have then only to observe when it begins and ends. It is also to be remarked, that these eclipses happen only about the time of the full moon, and even then not often.

From these circumstances it will readily appear, that if an eclipse of the moon be observed at any two places which lie under the same meridian, the clocks of those places, supposing them to be perfectly true, will show either the beginning or the end of the eclipse at the same time; but if the two places lie under different meridians, the clocks of those places will show the beginning or end to be at different times, according to their situations. An eclipse of the moon, therefore, being observed from any two places whatever, will furnish us with the means of discovering the longitude of those places. If, for instance, the time-pieces of one place, show the beginning of the eclipse to be at twelve o'clock, and the time-pieces of the other, at one, the difference of longitude between these two places will evidently be fifteen degrees; and so on, in the same proportion.

It will be necessary to remark, however, that these observations must be compared with those made at a place whose longitude is known, before we can determine the meridian under which we are situated. So that if I am upon some unknown part of the globe, the longitude of which I am desirous of discovering, and have an opportunity of making observations on an eclipse of the moon, these observations will be of no service to me, unless I can compare them with those made at London, or some other place whose situation is known. Some farther assistance is therefore requisite; for if I am obliged to wait till I return to London, it would not answer my purpose, as I want to inform myself upon the spot.

To obtain this information, we must have recourse to the theory of the moon, which is now so well understood, that we are not only able to foretel all the lunar eclipses that will happen in any given time, but can also calculate the beginning and end of those eclipses to the greatest degree of precision. In most of our common almanacs, they may be found according to the time at which they will happen at London; and in some other performances of this kind, they are computed for several years to come. In order, therefore, to find the longitude of any unknown place, in which I may happen to be, I have only to provide myself with one of these almanacs; and by comparing the time of the beginning or end of an eclipse, with the time as it is calculated for London, I can immediately find the difference between the meridian of London and that under which I am situated.

This method is, however, subject to several objections. Eclipses of the moon happen too seldom to be of any great service at sea; and, therefore, as the mariner is almost constantly in want of information, he must make use of some other means for obtaining it. Besides this, the beginning and end of an eclipse cannot be distinguished with sufficient exactness to be fully relied upon by the navigator; for as they arrive almost insensibly, it frequently happens, that we cannot be sure of having obtained the true time, to within less than two or three minutes. But as the error must be nearly the same for the beginning as the end, it may, in some measure, be avoided, by taking the mean time between the two observations, and comparing it with that shown by the almanac.

Eclipses of the sun, and occultations of the fixed stars, may likewise be employed for determining the longitude of places; but in a different manner from those of the moon, and by means of calculations that are too difficult and perplexing to admit of a familiar explanation. The reason of which is, that the sun is subject to no real deprivation of his light, but is only partially obscured by the interposition of the moon, which being now between the sun and the earth, prevents his rays from reaching us as at other times. The moon, likewise, appears to obscure the sun only to the inhabitants of some particular places, so that a solar eclipse may frequently be observed at London, while at Paris there is not the least indication of such a phænomenon. On the contrary, the moon is really deprived of her light, by the interposition of the earth, and, consequently, an appearance of this kind, may be seen at all places, where the moon is above the horizon at the time the eclipse happens.

From what has been said, you will easily perceive, that if any other of the celestial bodies were, from time to time, really deprived of their light, they might be employed to determine the longitude of places with the same success as eclipses of the moon. The satellites of Jupiter are bodies of this kind, whose eclipses afford us more frequent means of information than those of the moon: they pass so often into the shadow of that planet, that there is scarcely a night in which one or other of them is not eclipsed; and as they appear and disappear almost instantaneously, the time of the phænomenon, by means of a good telescope, may be much more accurately observed. The first and second satellites are esteemed the best for this purpose; for, besides that their theories are more accurately settled, they are quicker in their motions than either of the rest, and will, therefore, be more frequently eclipsed.

Jupiter, as I have already informed you, has four satellites, or moons, which revolve round him in different orbits, in the same manner as the moon revolves round the earth. A simple inspection of Pl. IV. fig. 13. will give you a perfect idea of the manner in which these satellites are eclipsed. S represents the sun, J Jupiter, SS his shadow, and 1, 2, 3, 4, the satellites, according to the order in which they move. When either of them enters into the shadow SS, it becomes immediately invisible; and the moment when it disappears, is called the immersion of that satellite. After being for some time totally hid from our sight, it again instantly appears on the contrary side of the shadow; and the moment when it becomes visible, is called the emersion of the satellite.

The immersions and emersions are both equally proper for determining the longitude; for as the appearances are the same at all places, where Jupiter is at a sufficient height above the horizon, the difference of time shown by the clocks and watches of those places, at the moment when either of these appearances are observed, will show the meridians under which they are situated. We have tables, ready calculated, to show the time when these eclipses will happen for the meridian of Greenwich, to a great degree of precision. Suppose now, an observer, who is provided with these tables, a good telescope, and a well regulated clock, has an opportunity of observing either the beginning or end of an eclipse of one of Jupiter's moons, from any part of the earth, where he may happen to be; he has only to note the precise time, at that place, when the satellite immerges into, or emerges out of Jupiter's shadow, and this time compared with that which is shown by the tables for Greenwich, will give the longitude required.

These eclipses are very convenient for finding the longitude at land, because they happen almost every day when Jupiter is visible; but unfortunately they are but of little use at sea, where a knowledge of this kind is most wanted; the rolling of the ship rendering it impossible to make nice telescopical observations with any degree of accuracy. If we could see the satellites of Jupiter with the naked eye, as well as we can the moon, the method would be attended with no difficulty; it might be practised by any common sailor on board, and the longitude would then be found with nearly as much ease and certainty as the latitude. We have several methods for finding the apparent time at any place by celestial observations; and if a good pocket watch be previously regulated by these means, the difference between the time when the phænomenon happens, as shown by the watch, and the time as shown by the tables, being converted into degrees, by allowing fifteen to an hour, will give the longitude of the place from London.

Several attempts have been made to adapt telescopes to the purposes of marine observations, but they have all hitherto failed of success; and there is reason to fear, that the obstacles which stand in the way of this improvement are such as cannot be removed. One of the methods which have been proposed for rendering the use of the telescope easy on board a ship, is by fixing a chair in such a manner that it shall not be agitated by the motions of the vessel; and if this could be accomplished, it would then be as easy to observe an eclipse at sea as at land. The late ingenious Mr. Irwin, contrived a machine of this kind, and laid claim to the parliamentary reward offered for the discovery of the longitude; but as it was judged to be defective, his hopes were disappointed, and his invention of course neglected.

Such are the difficulties with which this important subject is perplexed and embarrassed, that all the resources of art and genius have hitherto been ineffectual to remove them. By applying to the heavens, however, we have another method afforded us, which, although it be attended with some difficulties, is that in which astronomers at present have the greatest confidence, and hopes of success. This method is likewise derived from observations on the moon, not when she is eclipsed, but at any time whatever, when she is visible above the horizon of the place where the observations are to be made. Eclipses of the moon happen too seldom to be of any great service at sea, and the planet Jupiter is, for a great part of the year, invisible; but the moon is almost continually offering herself to our view. This method, therefore, appears to be better adapted to general use than any that has yet been discovered.

The moon rises about three quarters of an hour later every day than upon the preceding one; and as she changes her place considerably, from day to day, among the stars, these changes become proper for determining the longitude. If, for instance, the moon be observed to-day to be near any fixed star, she will appear to-morrow, at the same hour, to be at a considerable distance from it, towards the east; and, therefore, this motion, which, in some cases, is more than fifteen degrees in a day, will serve to mark any small portions of correspondent time with sufficient exactness. Now if the distance of the moon from any fixed star, together with the exact time, be observed at sea, and the time when it has the same distance be computed for the meridian of Greenwich, the difference between the computed time and the observed time, being turned into degrees, minutes, &c. will give the difference of longitude required.

In the Nautical Almanac, a work printed under the authority of the commissioners of longitude, for the purpose of facilitating astronomical computations, the distances of the moon from the sun, and from certain fixed stars, are ready computed for every day at noon, and every three hours afterwards, for the meridian of Greenwich; with a rule for finding the time, answering to any given distance whatever. Suppose now, that I am at sea, and want to find the longitude of the place I am in: I choose some remarkable fixed star, whose name and situation is known, and find, with a quadrant, the angular distance between that star and the moon; and by a watch, previously regulated for that purpose, the exact time when the observation was made. This being done, I look into the almanac, and find what time it is at Greenwich when the moon and star have the same distance; and this time, being compared with the time of observation, will, by allowing fifteen degrees to an hour, give the longitude of the place required.

The names and places of some of the brightest fixed stars, are to be found in a work entitled, "Tables requisite to be used with the Nautical Almanac," together with the methods made use of for obtaining their true distances from the moon at the time of observation. For it is to be noted, that the distance found by the quadrant, is not that which is to be used in determining the longitude, but the distance as it would appear to a spectator placed at the earth's centre. This is the distance as it is computed for Greenwich; and in order that they may agree, it must be determined in the same manner for the place of observation. The necessity of these operations will be sufficiently obvious, from the consideration of the earth's being a globe; but as the calculations upon which they depend, are deduced from the principles of spherical trigonometry, they can only be understood by those who have a knowledge of that subject.

This last method of finding the longitude, which is founded upon observations of the moon, is, by the general consent of astronomers, the best that has yet been discovered. And though it may not be easily practised by every common mariner, yet to a person of skill and abilities, the time and labour it requires are the principal objections against it. But as the success of any method, must depend upon the accuracy with which it can be practised, it may not be amiss to give you some idea of the degree of precision that we may hope to obtain in finding the longitude from lunar observations; or, which is the same thing, by taking the distance between the sun and moon, or between the moon and some remarkable fixed star.

In the first place then it may be observed, that the moon's daily motion in her orbit being about thirteen degrees, her hourly mean motion is about half a degree, or one minute of a degree in two minutes of time; so that if an error of one minute be committed in calculating the place of the moon, it will produce an error of two minutes in time, or half a degree of longitude. If the motion of the moon was more rapid than it is, it would afford us the means of attaining a still greater degree of perfection; and, on the contrary, if her motion was slower, so that we could scarcely discern her change of place from one day to another, we could receive no advantage from it in discovering the longitude.

It was not till within half a century past, that astronomers were able to calculate the place of the moon to within less than six or seven minutes of the truth; which error was so considerable, that no use could be made of lunar observations in discovering the longitude, either at sea or land. Sir Isaac Newton was the first who discovered the true cause of the inequalities in the moon's motion, which before his time were considered as inexplicable; and from the theory he has laid down, lunar tables are now computed with such extreme accuracy, that the place of the moon may be determined in any part of her orbit, to within less than a minute of the truth.(*k*)

But, besides the error here noted, several others will be apt to arise from the instrument and the observations. The most experienced observer cannot be sure that he has obtained the true lunar distance to within less than half a minute of the truth at least, and this, joined to the former one, will produce in the whole a mistake of three minutes in time, which is equivalent to three quarters of a degree of longitude. It will, however, conduce to a still greater degree of accuracy, if the moon's distance be taken from two stars, or from the sun and a star on each side of her, as often as opportunity permits; for as the imperfections of the instrument, as well as unavoidable small errors which attend the use of it, have a natural tendency to correct each other, the mean result, arising from these different observations, will generally be much nearer the truth than if either of them be taken separately.

This method of determining the longitude, by

(*k*) The most accurate tables of this kind are those of Bourg, published at Paris under the direction of the board of longitude, and since in English by professor Vince, in vol. iv. of his Astronomy.

means of the moon's distance from the sun and certain fixed stars, was first recommended, for its superior excellence, by the celebrated Dr. Halley, and has since been adopted by all the most eminent astronomers in Europe. The perfection, however, to which it is now arrived, is, in a great measure, owing to the exertions of Dr. Maskelyne, the late Astronomer Royal, to whom we are indebted for the publication of the Nautical Almanac, the Requisite Tables, and several other useful performances, which have been found of the utmost service to navigation.

LETTER XI.

OF THE DIFFERENT LENGTHS OF DAYS AND NIGHTS, AND THE VICISSITUDES OF THE SEASONS.

NATURE is always grand in her designs, but frugal in the execution of them: sublimity and simplicity are the striking characteristics of her operations. From a few simple principles she produces the most astonishing effects, and charms us no less by the infinite diversity of her operations, than by the skill and contrivance which are manifested in the performance of them. The sun, moon, planets and stars, are all governed by the same invariable laws; the single principle of gravitation pervades the whole universe, and puts every spring and wheel of it in motion. From the indiscernible atom, to the vast and immeasurable luminaries of heaven, every thing is subject to its dominating influence; and from this active, invisible, and invigorating agent, proceeds all that order, harmony, beauty and variety, which so eminently distinguishes the works of creation.

But of all the effects resulting from this admirable scene of things, nothing can be more pleasing and agreeable to a philosophic mind, than the alternate succession of day and night, and the regular return of the seasons.

———"Sweet is the breath of morn,
And sweet the coming on of grateful evening mild."

When the sun first appears in the horizon, all nature is animated by his presence; the magnificent theatre of the universe opens gradually to our view, and every object around us excites ideas of pleasure, admiration and wonder. After "riding in all his brightness" through the vault of heaven, he is again hid from our sight, and we are now presented with a new spectacle of equal grandeur and sublimity. The heavens are on a sudden covered with innumerable stars; "the moon rising in clouded majesty, unveils her peerless light;" whilst the silent solemnity of the scene, fills the mind with sentiments and ideas beyond the power of language to express.

Variety is the source of every pleasure; and the bountiful Author of nature, in the magnificent display of his wisdom and power, has afforded us every possible means of entertainment and instruction. What a pleasing succession of scenes results from the gradual vicissitudes of the seasons? Summer, winter, spring and autumn, lead us insensibly through the varied circle of the year; and are no less pleasing to the mind, than necessary towards bringing to maturity the various productions of the earth. Whether the sun flames in the solstice, or pours his mild effulgence from the equator, we equally rejoice in his presence, and bless that omniscient Being who gave him his appointed course, and prescribed the bounds which he can never pass.

These phænomena depend upon the most simple and evident principles; and as you will naturally be desirous of knowing in what way they are effected, I shall omit all further digressions, and proceed immediately to the illustration of the subject. In the first place, then, it is to be observed, that the alternate succession of day and night is occasioned merely by the uniform rotation of the earth upon its axis. For, as the globe turns regularly round upon this imaginary line, once in every twenty-four hours, and only one half of it can be illuminated at a time, it is evident that any particular place will sometimes be turned towards the sun, and sometimes from it, and being constantly subject to these various positions, will enjoy a regular return of light and darkness; as long as the place continues in the enlightened hemisphere it will be day, and when, by the diurnal rotation of the earth, it is carried into the dark hemisphere, it will be night.

The motion of the earth upon its axis, is from west to east; and this occasions an apparent motion of the celestial bodies in a contrary direction. The sun, for instance, seems to make his daily progress through the heavens from the east towards the west; but this is an optical delusion, arising from the opposite motion of the earth: for a spectator being placed in any part of the dark hemisphere, will, by the rotation of the earth upon its axis, be brought gradually into the enlightened one; and as the sun first appears to him in the east, it will seem to ascend higher and higher towards the west, in proportion as the spectator moves in a contrary direction towards the east: so that whether the earth turns round upon its axis once in twenty-four hours, or whether the sun and all the other celestial bodies, move round the earth in that time, the appearances will be exactly the same.

Every planet, whose situation is such as to admit of the necessary observations to be made on it, has been found to have a revolution upon its axis; and as this revolution is the cause of a constant succession of day and night to every part of their surfaces, so an inclination of the axis of any planet to the plane of its orbit, occasions the vicissitudes of the seasons. Thus, Jupiter, whose axis is nearly perpendicular to the plane of his orbit, has equal days and nights continually, from one pole to the other; their length being each four hours and twenty-eight minutes: but Venus, the Earth, and also Mars, according to the late discoveries of Dr. Herschel, having their axes inclined to the planes of their orbits, in an angle considerably less than that of ninety degrees, are subject to an annual change of their seasons, and to a great variety in the length of their days and nights.

As only one half of the globe can be enlightened at a time, the circle which is the boundary of light and darkness may be called the terminator; and it is evident, from a slight consideration of the subject, that if the axis of the earth was perpendicular to the plane of its orbit, the terminator would pass through the two poles, and divide each of the small circles, which are drawn parallel to the equator, into two equal parts. And as the uniform rotation of the earth upon its axis, must occasion every place to describe equal parts of one of these parallel circles in equal times, the days and nights would, of course, be equal all over the globe, except at the poles, where the sun would neither rise nor set, but remain continually in the horizon.

But, on the contrary, if the axis of the earth be inclined to the plane of its orbit, all the parallels, except the equator, will be divided by the terminator into two unequal parts, having a greater or less portion of their circumferences in the enlightened, than in the dark hemisphere, according to their respective situations on the globe, and the place of the earth in its orbit. So that those places situated in either hemisphere, which have their pole turned towards the sun, will have their days longer than their nights; and on the contrary, those places which lie in the opposite hemisphere, will have their nights longer than their days; whilst at the equator, the days and nights will be continually equal to each other.

But since the axis of the earth always remains parallel to itself, when the earth is in the opposite point of its orbit, the contrary pole will be turned towards the sun, and the parallels will be still unequally divided by the terminator; but the phænomena will be directly the contrary; all those places situated within the latter hemisphere, will now have their days longer than their nights, whilst those in the former will have their nights longer than their days; the days and nights at the equator being equal to each other, the same as before. And, as the disproportion is greatest in the higher latitudes, it is evident, that in either of these two positions of the earth, all those places which lie about the poles, must enjoy either a constant day or a constant night, since the diurnal rotation of the earth never carries them into the opposite hemisphere.

These observations being properly attended to, it will be easy to account for all the inequalities in the length of days and nights, and the change of seasons which arises from them. For this purpose, let S (Pl. v.) represent the sun, ABCD the earth's orbit, NS her axis, and the figures distinguished by the months March, June, September and December, four different positions of the earth in her annual motion round the sun. Then, since it is known from observation, that the axis of the earth is always directed to nearly the same fixed point in the heavens, it will constantly preserve the same position, and be always in a situation parallel to itself, in whatever part of its orbit the earth may be, in the course of its journey round the sun.

Suppose now, the earth to be in the situation which is represented by the month March; then, because a right line joining the centres of the sun and earth, will cut the surface of the earth in the equator, the terminator will pass through the two poles, and the days and nights will consequently be equal all over the globe. But when the earth, by its annual motion, is carried farther in its orbit towards A, the north pole N, of the axis, still continuing to observe the same parallel situation, will advance into the enlightened hemisphere, and, in the month of June, will be about twenty-three degrees and a half distant from the terminator, the south pole being at the same distance in the dark hemisphere. In the month of June, therefore, the northern parts of the earth will enjoy long days and summer, whilst the southern parts will have short days and winter.

During the interval between the time of equal days and nights in March, which is called the Vernal Equinox, and the time when the day is the longest in June, which is called the Summer Solstice, the north pole will have described a quarter of a circle in the enlightened hemisphere, and will then be at its greatest distance from the boundary of light and darkness. And whilst the earth moves forward in its orbit towards B, the days will gradually shorten, till it arrives at the position denoted by the month September, when, as the north pole has now described the other quarter of the circle, the terminator will again pass through the two poles, and the days and nights will be equal, as before.

This last situation of the earth is called the Autumnal Equinox, and the season is now a medium between summer and winter. And as the earth proceeds forwards in her orbit towards D, the days will shorten till December, when the north pole will be just as far in the dark hemisphere as it was in the enlightened one in June; at which time it is called the Winter Solstice. From the winter solstice, to the vernal equinox, the days will gradually lengthen, as the north pole approaches the terminator; and at the instant when it has again obtained that situation, the natural year, which consists of three hundred and sixty-five days, five hours and about forty-eight minutes, is exactly completed.

By the same explication, it is easy to perceive, that the inhabitants of the southern hemisphere must have the same vicissitudes with those in the northern, but in a contrary order, it being winter in one hemisphere whilst it is summer in the other. But lest this explanation of the subject should not be found sufficiently intelligible, I shall give you one of the most simple experimental illustrations of it I have yet seen; which is taken, with a few alterations, from Ferguson's Astronomy, where it appears to have been first proposed.

Take about seven feet of strong wire, and bend it into the circular form *abcd*, (Pl. VI.) which, in consequence of its being viewed obliquely, will appear elliptical, as in the figure. Place a lighted candle on a table, and having fixed the end of a silk thread K, to a small terrestrial globe H, of about three inches in diameter, cause another person to hold the wire circle *abcd*, so that it may be parallel to the table, and of the same height with the flame of the candle I, which should be nearly in the centre of the table.

Having twisted the thread towards the left hand, so that by its untwisting again, it may turn the globe eastward, or contrary to the way which the hands of a watch move, suspend the globe by the thread, within this circle, almost contiguous to it;

and as the thread untwists, the globe, which is enlightened half round by the candle, as the earth is by the sun, will turn round its axis, and the different places upon its surface, will be carried through the light and dark hemispheres, and have the appearance of a regular succession of day and night, in the same manner as would take place upon the earth, by means of such a motion.

As the globe turns by the untwisting of the string, move your hand slowly round the candle, according to the order of the letters *abcd*, keeping its centre continually even with the wire circle, and you will perceive that the candle, being still perpendicular to the equator, will enlighten the globe from pole to pole, through the whole of its motion round the circle; and that every place on the globe goes equally through the light and dark hemispheres, as it turns round by the untwisting of the string, and has, therefore, a perpetual equinox, or an equal portion of day and night.

The globe turning in this manner, represents the rotation of the earth upon its axis, and the motion of the globe round the candle the earth's annual revolution round the sun: it also shows, that if the axis of the earth had no inclination to the plane of its orbit, all the days and nights in the year would be equally long, and of course that there would be no variety of the seasons. This is exactly what would take place, if the earth moved in the equator instead of the ecliptic; but as that is not the case, we shall now see what effects will follow from its true motion in the circle last mentioned.

Desire the person who manages the wire circle to hold it obliquely, in the position ABCD, raising the side ♋ just as much as he depresses the side ♑, that the flame may be still in the plane of the circle; and, twisting the thread as before, that the globe may turn round its axis the same way that you carry it round the candle, that is, from west to east, let the globe down into the lowermost part of the wire circle at ♑; and, if the circle be properly inclined, the candle will shine perpendicularly on the tropic of Cancer, and the frigid zone, lying within the arctic or north polar circle, will be entirely in the light, as in the figure; and will always continue to be so, though the globe turn round its axis ever so often.

In this position of the globe, it is also evident, that all the places which lie between the equator and the north polar circle, have their days longer than their nights; and that all those places which lie between the equator and the south polar circle have just the reverse. The sun does not set to any part of the north frigid zone, as is shown by the candle's continually shining on it, so that the motion of the globe can carry no part of that zone into the dark; and, at the same time, the south frigid zone is involved in darkness, as the revolution of the globe can bring no part of it into the light.

If the earth were to continue in this part of its orbit, the sun would never set to the inhabitants of the north frigid zone, nor rise to those of the south frigid zone. At the equator it would always be equal day and night; and at places more distant from the equator, towards the arctic circle, they would have their days longer than their nights, whilst those on the south side of the equator would have their nights longer than their days; so that in this case, there would be continual summer on the north side of the equator, and continual winter on the south side of it.

But as the globe turns round its axis, move your hand slowly forwards, so as to carry it from H towards E, and the boundary of light and darkness will then approach towards the north pole, and recede from the south pole; the northern places will go through less and less of the light, and the southern places through more and more of it; which shows how the northern days decrease in length, and the southern days increase, whilst the globe proceeds from H to E.

When the globe is at E, it is at a mean situation between the lowest and highest parts of its orbit; the candle is directly over the equator; the boundary of light and darkness just reaches to both the poles; and all places on the globe go equally through the light and dark hemispheres; which shows that the days and nights are then equal on every part of the earth, the poles only excepted; and there, it is evident, the sun is setting to the north pole, whilst he is rising to the south pole.

Continue moving the globe forward, and as it goes through the quarter A, the north pole will recede farther into the dark hemisphere, and the south pole advance more into the light, as the globe comes nearer to ♋; and when the centre of it is at F, the candle will be directly over the tropic of Capricorn; so that the days are then at the shortest, and nights at the longest in every part of that hemisphere, from the equator to the arctic circle; and the reverse in the southern hemisphere, from the equator to the antarctic circle; within which circles, it is dark to the north frigid zone, and light to the south.

Continue both motions as before, and as the globe moves through the quarter B, the north pole advances towards the light, and the south pole recedes towards the dark; the days lengthen in the northern hemisphere, and shorten in the southern; and when the globe comes to G, the candle will be again over the equator, as it was at E, and the days and nights will be equal as before; so that the north pole will be just coming into the light, and the south pole going out of it.

From this experiment, we see the reason why the days lengthen and shorten from the equator to the polar circles every year; why there is sometimes no day or night for many revolutions of the earth, within the polar circles; and why the days and nights are equally long all the year round at the equator, which is always equally cut by the terminator, or the circle which is the boundary of light and darkness.—All this beautiful variety is occasioned by the inclination of the earth's axis to the plane of its orbit.

> "Some say he bid his angels turn askance
> The poles of earth twice ten degrees and more
> From the sun's axle: they, with labour, push'd
> Oblique the central globe." MILTON.

The earth's orbit being elliptical, and the sun constantly keeping in one and the same focus, which is about one million three hundred and seventy-seven thousand miles from the centre, the earth will, therefore, be two million seven hundred and fifty-four thousand miles nearer to the sun, at one time of the year than at another; and as the sun appears constantly larger, or under a greater angle in winter than in summer, it is evident that the earth must be nearer to the sun in the former season than in the latter. But here this question will naturally arise; Why have not we the hottest weather when we are nearest to the sun? The earth is above two millions of miles nearer to the sun in December than it is in June, and yet in June it is the middle of summer, and in December the depth of winter; this seems a paradox.

In answer to this apparent contradiction, it may be observed, that the excentricity of the earth's orbit, or one million three hundred and seventy-seven thousand miles, bears no greater proportion to her mean distance from the sun, than seventeen does to one thousand, and therefore can occasion but little difference in the heat and cold of different seasons. But the principal cause of this difference is, that the sun's rays, in winter, fall so obliquely upon us, and have so large a portion of the atmosphere to pass through, that they come with less force, and spread over a larger space than they do in summer, or when the sun is at a greater height above the horizon. In the winter long nights, we have also a greater degree of cold than can be compensated for by the return of heat in the short days; and on both these accounts the cold will be much increased. Whereas in summer, the sun's rays descend more perpendicularly upon us, and therefore fall with a greater force, and in a greater quantity, upon any particular place, than when they come more obliquely. The sun is also much longer above the horizon than in winter, and, consequently, a greater degree of heat will be imparted by day, than can fly off by night; so that the heat, on all these accounts, will continue to increase.

LETTER XII.

OF THE NATURAL AND ARTIFICIAL DIVISIONS OF TIME.

The more we extend our views, the more we are perplexed and embarrassed. Things which once appeared the most familiar to our understandings, are now hid under an impenetrable veil, and become totally mysterious and inexplicable. Education is a new birth to man; but, with all the advantages that art and nature can bestow, he is still a limited and confined being. Numberless are the questions that may be put to the most profound philosopher, which, if he be ingenuous, he must confess his entire inability to resolve. What, for instance, is time, space, matter, or motion? Every one, who speaks of these things, imagines himself to be clearly understood, even by the most illiterate; and yet if you require an explanation of the question, no one is able to give a rational answer to it.

If nobody asks me, said St. Augustine, what time is, I know; but if any body asks me, I do not know. Another philosopher being desired to explain the nature of motion, got up and walked. I cannot define it, said he, but I'll show you the thing itself. But of all the definitions that ever were given of motion, that of Aristotle is the most curious; who tells us that it is "the act of a being in power, as far as it is in power;" which, as Mr. Locke observes, is such a jargon, as would puzzle any rational person, who had not before heard it, to guess what word it could possibly be meant to explain.

Mr. Leibnitz defines time to be "an order of successions, as space is an order of coexistences;" and Hobbes, who is still more refined in his notions, calls space the "phantasm of a thing existing, as existing." What sort of satisfaction or conviction, these definitions afford the mind, you will readily perceive, by consulting your own bosom. The fact is, they are wholly unintelligible, and instead of conveying any clear ideas of the subject, serve only to render our simple and common notions of it more perplexed and obscure. No knowledge can be obtained from a definition, but when the terms made use of in the explication of it, are better understood than the thing itself; and that this is not the case in the present instance, is pretty obvious. The nature of time, is, indeed, so intricate, that, to me, it appears incapable of admitting a clear and explicit definition. We must explain it by means of the terms space, matter, and motion, and these are all equally mysterious and ambiguous.

The notion we attempt to form of Eternity, has ever been considered as one of the most perplexing and embarrassing conceptions of the human mind; but some modern speculators in metaphysical subtilties, pretend that there is nothing of which we have a more clear and determinate idea; and, with respect to time, they deny that there is any such thing; it being, as they say, only a particular modification of eternity, and has no distinct conceivable existence, independent of the subject of which it is an attribute or property. This is as much as to say, that finitude is more incomprehensible than infinitude; and that motion, which is the measure of time, cannot be conceived without it be first represented to the mind as being perpetual.

Dr. Young, in his melancholy rhapsody the Night Thoughts, has some curious poetical ideas upon this subject: he calls time heaven's stranger, and represents it as being born at the creation of the world.

> "That memorable hour of wondrous birth,
> When the dread Sire, on emanation bent,
> And big with nature, rising in his might
> Call'd forth creation, (for then time was born)
> By godhead streaming through a thousand worlds."

And again:

> "From old eternity's mysterious orb,
> Was time cut off, and cast beneath the skies;
> The skies, which watch him in his new abode,
> Measuring his motions by revolving spheres;
> That horologe machinery divine.
> Hours, days, and months, and years, his children, play
> Like numerous wings around him, as he flies:
> Or rather, as unequal plumes, they shape
> His ample pinions, swift as darted flame,
> To gain his goal, to reach his ancient rest,
> And join anew eternity his sire."

What is to be understood from this passage it is not easy to say. The book, however, contains much better things; some of his thoughts being highly sublime and poetical: but his philosophical notions are, in general, affectedly mysterious and obscure.

I have mentioned these things, merely to show you what insuperable difficulties we have to encounter, when we attempt to carry our speculations and enquiries beyond their assigned bounds. Properties and effects are all that we are acquainted with: the nature and causes of things are entirely hid from us, and it is in vain to seek after them. The celebrated Maclaurin, whose mind was as elegant and refined, as it was penetrating and comprehensive, does not, whilst he is treating on this subject, attempt to give a strict and scientific definition of time. After making a number of judicious observations upon the certainty we have of our own existence, and the manner in which external objects act upon the mind, he expresses himself as follows.

"From the succession of our own ideas, and from the successive variations of external objects in the course of nature, we easily acquire the ideas of duration and time, and of their measures. We conceive true or absolute time, to flow uniformly in an unchangeable course, which alone serves to measure with exactness the changes of all other things. For unless we correct the vulgar measures of time, which are gross and inaccurate, by proper equations, the conclusions are always found to be incorrect and erroneous. Time may be conceived to be divided into successive parts that may be less and less without end, though, with respect to any one particular being, there may be a least sensible time, as well as a *minimum sensibile* in other magnitudes. But however various the flux of time may appear to different intellectual beings, it cannot be thought to depend upon the ideas of any created being whatever."

Time is in a perpetual flux, and perishing; but a representation of it is preserved in the space described by motion. As the sun, therefore, is the most conspicuous body in our system, and appears to move regularly through the heavens, his motion is naturally fixed upon as one of the properest measures of time that is afforded us by nature. It is by means of his apparent diurnal and annual revolutions, that we obtain the two grand divisions of time, into days and years; and thence all the different periods that are at present in use. The first division of the day was simply into four parts, morning, noon, evening, and midnight; but as these measures are vague and uncertain, art has been called in to our assistance, and has furnished us with instruments, by which we are enabled to measure small intervals of time with greater precision.

In like manner, by combining the revolutions of the sun and moon we embrace the larger intervals, and, by that means, form an idea of those grand periods of time, which, by a continual and rapid succession, have given birth to so many great events. But as these depend upon principles, which will be better explained hereafter, I shall content myself, at present, with only pointing out to you such other divisions, as arise from astronomical considerations, and which are principally used in that science. In all civil computations, a day is usually divided into twenty-four hours, reckoning twelve from midnight to noon, and twelve from noon to midnight again; but an astronomical day, is the interval between noon and noon, or the time elapsed between two successive transits of the sun's centre over the same meridian. This day is also divided into twenty-four hours like the former; but instead of stopping at twelve, as in the civil account, astronomers always reckon on from one to twenty-four, without interruption; so that, for instance, what is called seven o'clock in the morning of April the tenth, by the civil reckoning, is called, by astronomers, April the ninth, at nineteen hours.

The sun, as has been already observed, appears to go round the earth in twenty-four hours, and the fixed stars in twenty-three hours, fifty-six minutes and four seconds; so that they are found to gain three minutes and fifty-six seconds upon the sun every day; which amounts to one diurnal revolution in a year: and, therefore, in three hundred and sixty-five days, as measured by the returns of the sun to the meridian, there are three hundred and sixty-six days, as measured by the returns of the stars to the meridian; the former of which are called Solar days, and the latter sidereal. This difference between the solar and sidereal days, is occasioned by the immense distance of the fixed stars; for the earth's orbit, when compared with this distance, is but as a point; and therefore any meridian will revolve from a fixed star, to that star again, in exactly the same time as if the earth had only a diurnal motion, and was to remain for ever in the same part of its orbit.

But this is not the case with respect to the sun; for as the earth advances almost a degree eastward in its orbit, in the same time that it turns eastward round its axis, or completes its diurnal revolution, whatever star passes over the meridian any day with the sun, will pass over the same meridian the next day when the sun is three minutes and fifty-six seconds in time, or near a degree, short of it. If the year contained exactly three hundred and sixty days, as the ecliptic does three hundred and sixty degrees, the sun's apparent place, so far as his motion is equable, would change a degree every day; and, in this case, the sidereal days would be just four minutes shorter than the solar ones.

This matter may perhaps be made something plainer by means of a figure. For this purpose, let ABCD, &c. (Pl. VII. fig. 2.) be the earth's orbit, in which it goes round the sun every year, from west to east, according to the order of the letters; and turns round its axis, the same way, from the sun to the sun again, in twenty-four hours. Let S, in like manner, represent the sun, and R a fixed star, at such an immense distance, that the diameter of the earth's orbit bears no sensible proportion to that distance; also, in the figure N*nm*, which represents the earth in different points of its orbit, let N*m*, be any particular meridian, and N a given point, or place upon the surface of the earth, lying under that meridian.

These things being premised, it is plain that when the earth is at A, the earth, sun, and star will be all in the same right line; and, consequently, as the earth turns round its axis, the point N will come to the sun and star at the same time. But when the earth has advanced through a twelfth part of its orbit, from A to B, its motion round its axis will bring the point N a twelfth part of a day, or two hours, sooner to the star than to the sun. For the star, as has been already observed, will come to the meridian in the same time as if the earth had continued in its former situation, at A; but the point N must revolve from N to *n*, before it can have the sun upon its meridian. The arc N*n*, therefore, being the same part of a whole circle as the arc A B, it is plain that any star which comes to the meridian at noon with the sun, when the earth is at A, will come to the meridian at ten o'clock in the forenoon, when the earth is at B.

When the earth has passed from A to C, through a sixth part of its orbit, the point N will have the star upon its meridian at eight o'clock in the morning, or four hours sooner than it comes round to the sun; and, in like manner, when the earth has advanced forwards to D, through a fourth part of its orbit, the point N will have the star on its meridian at six o'clock in the morning; for as the earth has now proceeded through ninety degrees, or a fourth part of the whole circumference, it must likewise turn ninety degrees upon its axis, in order to carry the point N from the star to the sun; for the star will always come to the meridian when N*m* is parallel to RSA, because DS, the radius of the earth's orbit, is but as a point in respect to the immense distance RS.

When the earth is at E, the star will come to the meridian at four o'clock in the morning; at F at two in the morning; and at G, at midnight; for the earth having now gone just half round its orbit, the point N will be directly opposite to the sun; and, therefore, by means of the earth's diurnal motion, the star will come to the meridian twelve hours before the sun. In like manner, when the earth is at H, the star will come to the meridian at ten o'clock in the evening, or fourteen hours before the sun; at I, it will come to the meridian sixteen hours before the sun; at K, eighteen hours before him; at L, twenty hours; at M, twenty-two; and at A, it will return to the meridian at the same time, and be exactly with the sun again.

The daily revolution of the earth, which, by observation, is known to be uniform (*l*), is always completed, when any particular meridian is exactly parallel to the situation which it had at any time of the preceding day. And it is plain, from the figure, that the same meridian can never be brought round, from the sun, to the sun again, by one en-

(*l*) It may here be observed, that some able astronomers, have lately suspected that this motion is not perfectly uniform; but at all events it is so nearly so, that no sensible error can arise in considering it as such.

tire revolution of the earth upon its axis, but that it will require as much more of another revolution as is equivalent to the space she has advanced in her orbit during that time; which, at a mean rate, is the three hundred and sixty fifth part of a circle. So that in three hundred and sixty-five days, the earth will have turned three hundred and sixty-six times round her axis; and, therefore, as one complete rotation makes a sidereal day, there will be one sidereal day in a year more than there are solar days, be that number what it may, either on the earth, or on any other planet.

This regular return of the fixed stars to the meridian, affords us any easy method of determining whether our clocks and watches go true. For if, through a small hole in a window shutter, or in a thin plate of metal properly fixed for that purpose, we observe at what time any star disappears behind a chimney, or the corner of a building, at a small distance; then, if the same star disappears, the next night, three minutes and fifty-six seconds sooner, by the clock or watch, than it did the night before; on the second night seven minutes fifty-two seconds sooner; on the third night eleven minutes forty-eight seconds sooner; and so on; it is a certain sign that the machine goes right; but if it does not observe this rule, it is evidently not true, and must therefore be regulated accordingly: and as the disappearing of a star is instantaneous, we may depend upon this information to half a second at least.

Besides the divisions of time here mentioned, there are two others which relate to the year; and as they are frequently referred to by astronomers, it will not be improper to explain them. The two opposite points in which the ecliptic intersects the equator, are called the equinoctial points; and the two points where it touches the tropics the solstitial points; and the time elasped between two successive passages of the sun through the same equinoctial or solstitial points, is called the tropical year; which, by observation, is found to contain three hundred and sixty-five days, five hours, forty-eight minutes, and forty-five and a half seconds.

And, in like manner, as the tropical year is determined by the returning of the sun to the same point of the ecliptic, so the time elapsed between his departure from any fixed star and his returning to that star again is called the sidereal year, which contains three hundred and sixty-five days, six hours, nine ninutes, and fourteen seconds and a half. The sidereal year is therefore, twenty minutes, seventeen seconds and a half longer than the solar or tropical year; and nine minutes, fourteen seconds and a half longer than the civil year, which is three hundred and sixty-five days, six hours; so that the civil year is almost a mean between the sidereal and tropical years.

LETTER XIII.

OF THE EQUATION OF TIME; OR THE DIFFERENCE BETWEEN MEAN TIME AND APPARENT.

It is a circumstance worthy of observation, that, excepting the rotation of the earth upon its axis, there is no one body in nature, with which we are acquainted, whose motion is perfectly uniform and regular(*m*). The sun, in his apparent journey through the heavens, is supposed by the vulgar to furnish us with an accurate and just measure of time; but in this they are greatly mistaken. Astronomers have found that the motion of the sun is very unequal; and therefore equal time, which flows on for ever in the same manner, cannot be truly measured by the sun's motion. Mean, or equal time, is that which is shown by a perfectly well regulated clock or watch; and in order that the apparent time, as shown by a true sun-dial, may agree with this, it must be corrected by proper equations.

The difference between mean and apparent time depends upon two causes, the obliquity of the ecliptic with respect to the equator, and the unequal motion of the earth in an elliptical orbit. I shall first explain the effects of these causes separately considered, and then the united effects resulting from their combination. But, before we

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(*m*) See the observation that has been made upon this part of the subject, in page 189.

proceed to these particulars, it will be proper to remind you, that whenever the motion of the sun is spoken of, it is not to be understood in a positive sense, as if he actually removed from one part of space to another, but only as an appearance occasioned by the real motion of the earth in a contrary direction. The phænomena are exactly the same; and astronomers sometimes mention one, and sometimes the other, according as they find it most convenient for their purpose.

This being premised, it may be observed, that since the earth's axis is perpendicular to the plane of the equator, any equal portions of this circle, will, by means of the earth's rotation upon its axis, pass over the meridian in equal times; and so, in like manner, would any equal portions of the ecliptic, provided it were parallel to, or coincident with the equator. But as this is not the case, the daily motion of the earth upon its axis will carry unequal portions of it over the meridian in equal times; the difference being always proportional to the obliquity: and, as some parts of the ecliptic are much more obliquely situated with respect to the equator than others, those differences will be unequal amongst themselves.

Suppose, for example, that the sun and a star were to set out together from one of the equinoctial points, and to move continually through equal arcs in equal times; the star in the equator, and the sun in the ecliptic: then it is plain that the star, moving in the equator, would always return to the meridian exactly at the end of every twenty-four hours, as measured by a well regulated clock, that keeps equal time; but the sun, moving in the ecliptic, would come to the meridian, sometimes sooner than the star, and sometimes later, according to their relative situations; and they would never be found upon that circle exactly together, except on four days of the year; namely, on the 20th of March, when the sun enters Aries; on the 21st of June, when he enters Cancer; on 23d of September, when he enters Libra; and on the 21st of December, when he enters Capricorn.

But lest a verbal description should be found insufficient, I shall endeavour to make it more intelligible by means of a figure. For this purpose, let Z ♈ z ♎ (Pl. VII. fig. 3.) be the earth; ZFRz its axis; *abcd*, &c. the equator; ABCD, &c. the northern half of the ecliptic, from ♈ to ♎, on the side next to the eye; and MNOP the southern half, on the opposite side, from ♎ to ♈. In like manner, let A, B, C, D, &c. be the boundaries of equal portions of the ecliptic, gone through in equal times by the sun; and *a*, *b*, *c*, *d*, &c. equal portions of the equator, described in equal times by the star; also let Z ♈ z be the meridian.

Then, as the sun moves obliquely in the ecliptic, and the star directly in the equator, a degree, or any number of degrees, between ♈ and F on the ecliptic, must be nearer to the meridian Z ♈ z, than a degree, or any corresponding number of degrees on the equator, from ♈ to *f*; and the more so as they are more oblique. The sun, therefore, comes to the meridian sooner every day, whilst he is in the quadrant ♈ F, than the star does in the quadrant ♈ *f*; and, as the motion of the fictitious star in the equator, answers to the motion of a well regulated clock, it is plain that the solar noon, in this case, will precede the noon by the clock.

On the contrary, whilst the sun describes the second quadrant of the ecliptic FGHIKL, from ♋ to ♎, he will come later to the meridian every day than the star, which moves through the second quadrant of the equator, from *f* to ♋; for the points G, H, I, K, L, being farther from the meridian than the corresponding points *g*, *h*, *i*, *k*, *l*, they must be later in coming to it; and as the sun and star arrive at the point ♎ at the same moment, they must then both come to the meridian together at the instant when it is noon by the clock.

Again, in departing from Libra, through the third quadrant, the sun going through MNOPQ towards ♑, and the star through *mnopq*, towards *r*; the former will come to the meridian every day sooner than the latter, till the sun arrives at the point ♑, and the star at the point *r*, and then they will both come to the meridian at the same time. And, in like manner, as the sun moves through the fourth quadrant STUVW, from ♑ towards ♈, and the star through the quadrant *stuvw*, from *r* towards ♈, the former will come later every day to the meridian than the latter, till they both arrive at the point ♈, and then they will make it noon at the same time with the clock.

This part of the equation of time, may be made still more familiar by means of a globe; for if a small black patch be put on every tenth or fifteenth degree, both of the equator and ecliptic, beginning at the point ♈, and the globe be turned round slowly to the westward, you will observe that all the patches from Aries to Cancer, and from Libra to Capricorn, will come to the meridian sooner than their corresponding patches on the equator; and all those from Cancer to Libra, and from Capricorn to Aries, will come to the meridian later than their correponding patches on the equator: whilst the patches at the beginning of Aries, Cancer, Libra, and Capicorn, being on, or even with those on the equator, show that the sun and star, will either meet there, or are even with each other, and, for that reason, must come to the meridian at the same time.

Mr. Ferguson, whom I have chiefly followed in this article, proposes the following method for showing the difference between solar, sidereal, and equal time. Suppose two little balls are made to move equally round a celestial globe, by means of clock-work; one always keeping in the ecliptic, and gilt with gold, to represent the real sun; and the other, keeping always in the equator, and silvered, to represent a fictitious sun; and let it be so contrived, that whilst these two balls move once round the globe, according to the order of the signs, the globe shall be made to turn three hundred and sixty-six times round its axis, westward.

Then, as the motion of the globe is uniform, any fixed star will come to the meridian in equal times, and make in all three hundred and sixty-six revolutions, from the brazen meridian to the brazen meridian again. But the two balls, representing the real and fictitious suns, going continually farther eastward from any given star, will come later than that star to the meridian every following day than on the preceding one; so that each ball will make in all exactly three hundred and sixty-five revolutions; and they will both come together to the meridian, at the beginnings of Aries, Cancer, Libra and Capricorn; but in every other point of the ecliptic, the gilt ball will come sooner or later to the meridian than the silvered ball, in the same manner as the patches above-mentioned.

This is an easy way of showing the reason why any given star, which, on a certain day of the year, comes to the meridian with the sun, passes over it so much sooner every following day, as on that day twelvemonth to come to the meridian with the sun again; and also, why the sun, moving in the ecliptic, comes to the meridian, sometimes sooner, and sometimes later than when it is noon by the clock; and on four days of the year at the same time; whilst a body, moving in the equator, would always come to the meridian exactly when it was noon by the clock. An ingenious artist might easily put this appendage to a celestial globe; for the gold ball might be carried round the ecliptic, by a wire from its north pole, and the silver ball round the equator, by a wire from its south pole, by means of a few wheels to each.

From what has been already said upon this subject, it it plain, that if the ecliptic cut the equator still more obliquely, as is represented by the dotted circle ♈ *x* ♎, (Pl. VII. fig. 3.) the equal divisions from ♈ to *x*, would come still sooner to the meridian z ♈ z, than those marked A, B, C, D, E; for two divisions, containing thirty degrees, from ♈ to the second dot, a little short of the figure I, will come sooner to the meridian than one division, containing only fifteen degrees, from ♈ to A; whilst those of the second quadrant, from *x* to ♎, would come so much later to it. In the third quadrant the same things would take place as in the first, and in the fourth as in the second; and where the ecliptic is most oblique, about Aries and Libra, it is evident, that the difference would be greatest; and least about Cancer and Capricorn, where the obliquity is least.

Having explained one cause of the difference of time, as shown by a well regulated clock and a true sun-dial, I shall now proceed to the other, and endeavour to make that equally easy and intelligible. The obliquity of the ecliptic is not the only cause of an inequality in the length of days, but this inequality arises also from the unequal motion of the sun himself. This motion is slowest in summer, when the earth is farthest from the sun, and swiftest in winter, when he is nearest to it; as is evident from the laws of Kepler, explained in Letter VI; by which it has been found, that the earth is about eight days longer in passing through the northern than through the southern half of his orbit: hence, although there were no obliquity of the ecliptic, the motion of the sun would not be a true and exact measure of time. For this motion sometimes exceeds a degree in twenty-four hours, and is sometimes less; and, consequently, when it is slowest, any particular meridian will come round sooner to him than when it is swiftest; so that the days, from this cause alone, cannot be equal to each other.

If two bodies, therefore, were to move in the plane of the ecliptic, so as to go exactly round it in a year; the one describing an equal arc every twenty-four hours, and the other describing sometimes a less arc in that time and sometimes a greater, gaining at one time of the year what it lost at another, it is evident, that one of those bodies would come sooner or later to the meridian than the other, according to their situations: and when they were both in conjunction, they would come to the meridian at the same instant. But as this may not be readily understood, it will, perhaps, appear more evident by means of a figure.

For this purpose, let ABCD (Pl. VII. fig. 4.) be the ecliptic, or the elliptical orbit which the sun, by an irregular motion, describes in the space of a year; and the dotted circle *abcd* the orbit of an imaginary star, coincident with the plane of the ecliptic, and in which it moves through equal arcs in equal times. Let HIK, also, be the earth, which revolves round its axis, every twenty-four hours, from west to east; and suppose the sun and star to set out together from A and *a*, in a right line with the plane of the meridian EH; the sun at A, being at his greatest distance from the earth; at which time his motion is slowest; and the star at *a*, whose motion is equable, and its distance from the earth always the same.

Then, because the motion of the star is always uniform, and the motion of the sun, in this point of his orbit, is the slowest, it is evident that whilst the meridian revolves from H to H, according to the order of the letters H, I, K, L, the sun will have proceeded forward in his orbit from A to F; and the star, moving with a quicker motion, will have gone through a larger arc, from *a* to *f*: from which it is plain, that the meridian EH will revolve sooner from H to *h*, under the sun at F, than from H to *k*, under the star at *f*; and consequently it will be noon by the sun, sooner than by the clock.

As the sun moves from A towards C, the swiftness of his motion will continually increase, till he comes to the point C, where it will be the greatest. But the star, notwithstanding this, will gain so much upon the sun, soon after his departure from A, that the increasing velocity of the sun will not bring him up to the equally moving star, till the former comes to C, and the latter to *c*; or when each of them has gone just half round its respective orbit; and as they are then in conjunction, the meridian EH, revolving to EK, will come to the sun and star at the same time; and consequently it is noon by them both at the same instant.

From this point, the increased velocity of the sun being now the greatest, will carry him before the star; and, therefore, the same meridian will, in this situation, come to the star sooner than to the sun. For whilst the star moves from *c* to *g*, the sun will move through a greater arc, from C to G; and, consequently, the point K has its noon by the clock when it comes to *k*, but not its noon by the sun till it comes to *l*. And though the velocity of the sun diminishes all the way from C to A, and the star, by an equal motion, is still coming nearer to the sun, yet they will not be in conjunction till the one comes to A, and the other to *a*, and then it is noon by them both at the same instant.

From this it appears, that the solar noon is always later than the noon by the clock, whilst the sun goes from C to A; and sooner whilst he goes from A to C; and at these two points, the sun and clock being equal, it is noon by them both at the same time. The point A is called the Sun's Apogee; because when he is in this situation, he is at his greatest distance from the earth; and the point C is called his Perigee; on account of his being then at his least distance from the earth: and a line A E C, drawn through the earth's centre, from one of these points to the other, is called the Line of the Apsides.

It may also be observed, that the distance which the sun, at any time, has gone from his Apogee, and not the distance he has to go to it, though it be ever so little, is called his mean Anomaly; and is always reckoned in signs, degrees, minutes, &c. allowing thirty degrees to a sign. Thus, for example, when the sun has gone a hundred and seventy-four degrees from his apogee at A, he is said to be five signs twenty-four degrees from it, which is his mean anomaly. And, in like manner, when he has gone three hundred and fifty-five degrees from his apogee, he is said to be eleven signs twenty-five degrees from it; although he be but five degrees short of A, in coming round to it again.

So that from what has been said, it appears, that when the sun's anomaly is less than six signs, that is, when he is any where between A and C, in the half of his orbit ABC, the solar noon will precede the clock noon: but when his anomaly is more than six signs, that is, when he is any where between C and A, in the half of his orbit CDA, the clock noon will precede the solar noon. On the contrary, when his anomaly is 0 signs 0 degrees, that is, when he is in his apogee at A; or, when it is exactly six signs, which is when he is in his perigee at C, he will come to the meridian at the same time with the star, and it will be noon by them both at the same instant.

The obliquity of the ecliptic to the equator, which is the first mentioned cause of the equation of time, would make the sun and clocks agree on four days of the year, which are when he enters Aries, Cancer, Libra, and Capricorn; but the other cause, which arises from his unequal motion in his orbit, would make the sun and clocks agree only twice a year, that is when he is in his apogee and perigee; and, consequently, when these two points fall in the beginnings of Cancer and Capricorn, or of Aries, and Libra, they will concur in making the sun and clocks agree in those points. But the apogee, at present, is in the ninth degree of Cancer, and the perigee in the ninth degree of Capricorn; and, therefore, the sun and clocks cannot be equal about the beginnings of those signs, nor at any other time of the year, except when the swiftness or slowness of equation, resulting from one of the causes, just balances the slowness or swiftness arising from the other.

About the first of November, the absolute equation of time resulting from both these causes will be the greatest; the time shown by an equally going clock being then about sixteen minutes and a quarter slower than the time shown by the sun. And, as this equation is of the utmost importance in all computations where time is concerned, astronomers have calculated tables, by which it may be found for every day of the year. So that by means of these tables we can always correct the apparent time, by reducing it to mean time, which is the principal end, or object proposed. For though the time shown by the sun appears to be the most obvious and natural, yet it is of no other use, but as it may be employed in finding the mean time, or that whose essence is equality or perfect uniformity; all the celestial revolutions, and every other epoch and period, being always referred to this standard, which is properly considered as the only true and adequate measure of duration.

The equation of time was known as early as the time of Ptolemy, as appears from what he has said upon this subject in the 3d Book of his Almagest; but notwithstanding it was employed both by Tycho Brahe and Kepler, it was not generally adopted till the year 1672, when Flamsteed published a dissertation upon the subject, at the end of the works of Horrox. Since that time, it has been found that some irregularities are also occasioned by the attractions of the planets; but as they depend upon principles which are not easily explained, and can, in no case, produce an error of more than a few seconds, I have altogether omitted them.

As the sun's place and anomaly are subject to continual variations, no general equation Tables can be so constructed as to be perpetual; and, therefore, when great accuracy is required, reference must be had to the Nautical Almanac, or some other performance of that kind. The following concise Table, however, which is adapted to the 2d year after Leap Year, will always be found within about a minute of the truth, and is, therefore, sufficiently accurate for the regulating of common clocks and watches, which are only divided into minutes.

Months.	Days.	Equ. in Minutes.	Months.	Days.	Equ. in Minutes.	Months.	Days.	Equ. in Minutes.	Months.	Days.	Equ. in Minutes.
Jan.	1	4 +	Apr.	1	4 +	Aug.	9	5 +		27	16 −
	3	5		4	3		15	4	Nov.	15	15
	5	6		7	2		20	3		20	14
	7	7		11	1		24	2		24	13
	9	8		15	0		28	1		27	12
	12	9		*	——		31	0		30	11
	15	10		19	1 −		*	——	Dec.	2	10
	18	11		24	2	Sept.	3	1 −		5	9
	21	12		30	3		6	2		7	8
	25	13	May	13	4		9	3		9	7
	31	14		29	3		12	4		11	6
Feb.	10	15	June	5	2		15	5		13	5
	21	14		10	1		18	6		16	4
	27	13		15	0		21	7		18	3
Mar.	4	12		*	——		24	8		20	2
	8	11		20	1 +		27	9		22	1
	12	10		25	2		30	10		24	0
	15	9		29	3	Oct.	3	11		*	——
	19	8	July	5	4		6	12		26	1 +
	22	7		11	5		10	13		28	2
	25	6		28	6		14	14		30	3
	28	5					19	15			

Where it is to be observed, that those columns which are marked + show that the clock or watch is faster than the sun, and those marked − that it is slower.

LETTER XIV.

OF THE REFORMATION OF THE CALENDAR.

One of the first cares of every society, after providing for its most pressing wants and necessities, has always been to establish some uniform method of reckoning time. Without such a standard to refer to, as occasion requires, the administration of public affairs, and the common concerns of life, would be subject to perpetual confusion. A well regulated calendar is, therefore, a matter of the most extensive utility and importance. It is by this means, that we are able to ascertain the returns of the seasons, and to point out the proper times for cultivating the earth; to adjust the observance of civil and ecclesiastical institutions, and to transmit to posterity the dates of such events as are worthy of remembrance.

A computation of time by certain regular periods, is a custom that has been observed by all nations, where arts and sciences have been cultivated; but as nature has afforded us no fixed or permanent measure of duration, the manner of estimating those periods has been various and uncertain. In some countries the natural day is supposed to commence with the rising of the sun, and in others with his setting; some begin to reckon from midnight, and others from noon. The Jews and Romans divided the artifical day into twelve parts, whether long or short, and the night in the same manner; so that their hours, except at the equinoxes, were always unequal; which custom, notwithstanding its manifest absurdity, is still followed by the Turks and other eastern nations.

The Egyptians, according to Herodotus, were the first who fixed the length of the year, and made it to consist of three hundred and sixty days, which they separated into twelve months, in order that it might agree with the course of the moon. Mercury Trismegistus added five days more; and Thales is said to have done the same thing among the Greeks. But the Jews, Syrians, Ethiopians, Romans, Persians, and Arabs, had all years of different lengths. The apparent vicissitudes of the seasons, occasioned by the various positions of the sun, seem to have first given occasion to this institution; and as the length of the period would be naturally adapted to comprehend all the varieties of this kind that could possibly happen, so their principal care would be to make the same parts of the year agree with the same seasons. But as different nations would make use of different methods, they would not all choose the same point of the ecliptic for the beginning of the year, nor be entirely agreed about the exact time of the revolution.

The day on which the year commences, is, also, different in different countries. The Romans, after the first regular adjustment of their calendar, agreed to begin their year on the first of January; which custom has since been observed by the English, and some other European nations. The Mahometans begin their year on the day when the sun enters the Ram; the Persians in the month which answers to our June; the Chinese and Indians with the first new moon that happens in March; and the Mexicans, according to d'Acosta, begin their year on the twenty-third of February, about which time the verdure, in that country, first begins to appear. It may here also be remarked, that, among the Romans, the first and last days of the year, were consecrated to Janus, which seems to be the reason why he is always represented with two faces; one looking forwards to the new year, and the other backwards on the old.

The week is another division of time, of the highest antiquity, which, in almost all countries, has been made to consist of seven days; a period supposed by some to have been traditionally derived from the creation of the world; whilst others imagine it was regulated by the phases of the moon. But whatever it might be that led so many different nations to adopt this primitive measure, it was certainly not universally received. The week of the ancient Greeks, according to Gassendus, consisted of ten days, and that of the Romans of nine; but afterwards, in imitation of the Jews, they divided it into seven; which custom was first introduced among the Romans about the time of the emperor Theodosius. Dies Solis, Lunæ, Martis, Mercurii, Jovis, Veneris, and Saturni, are the days of the Roman week, and the names of the seven planets; and so, among us, Saturday, Sunday, and Monday, plainly denote, Saturn's day, the Sun's day, and the Moon's day; and Tuesday, Wednesday, Thursday and Friday, are the days of Tuisco, Woden, Thor and Friga, which are the Saxon names for Mars, Mercury, Jupiter and Venus.

But of all the divisions of time, which have been in general use, the month and the year are the most embarrassing. To determine these periods with accuracy and precision, and to adjust them to the course of nature, is a matter of the utmost difficulty, and is yet far from being accomplished. The revolution of the moon in her orbit, or the time from one new moon to another, may be called a month; and the time the sun takes to perform his apparent course round the earth, from any one point in his orbit, to the same point again, may be called a year; but as neither of these revolutions are completed in an exact number of days, how are they to be reconciled with the common account of time, and made to agree with each other? The seasons are evidently regulated by the course of the sun; and as their returns are only to be known by means of his motion, it is from this alone that the proper length of the year can be determined.

In matters of little moment, the uninstructed part of mankind regard the powers of science with astonishment; but when the subject is beyond the reach of all science, they frequently imagine it to be attended with no difficulty. This has been particularly the case, with the attempts that have been made to correct the vulgar methods of reckoning time. The populace of every country, consider the year as a certain regular period, the length of which is pointed out by nature herself; and, with a clamour that bids defiance to reason, oppose every alteration. To change the observance of certain religious feasts, which have been long fixed to particular days, is looked upon as an impious innovation; and though the times of the events, upon which those ceremonies depend, be utterly unknown, it is still insisted upon that the Glastonbury thorn blooms upon Christmas-day, and that this country has never flourished since that festival was altered.

Popular prejudices have been nearly the same in all ages. The ancient calendar was so obviously defective, that it was impossible not to perceive the disorder it occasioned; and yet the multitude were still averse to reformation. Aristophanes, in his comedy of the Clouds, has a number of pleasantries upon this occasion. An actor, who was just come from Athens, recounts that he met with Diana, or the moon, and found her extremely incensed, that they did not regulate her course better. She complained, that the order of nature was changed, and every thing turned topsy turvy. The Gods no longer knew what belonged to them; but, after paying their visits upon certain feast-days, and expecting to meet with good cheer, as usual, they were under the disagreeable necessity of returning back to heaven again without their suppers.

Amongst the Greeks and other ancient nations the length of the year was generally regulated by the course of the moon. This luminary, on account of the different appearances which she exhibits at her full and change, and at her quarters, was considered by them as the best adapted of any of the celestial bodies for this purpose. And as one lunation, or revolution of the moon round the earth, was found to be completed in about twenty-nine days and a half, and twelve of these lunations being imagined to be nearly equal to one revolution of the sun, their months were made to consist of twenty-nine and thirty days alternately, and their year of three hundred and fifty-four days. But as the time between two successive full moons is now known to be twenty-nine days, twelve hours, forty-four minutes and three seconds, and the time the sun takes to move from one of the solstitial points to the same point again, is three hundred and sixty-five days, five hours, forty-eight minutes and fifty-one and a half seconds; it is evident, that this computation, although it agreed tolerably well with the course of the moon, must yet have been extremely defective, the difference between the lunar year and the true solar year, being more than eleven days.

The irregularities which such a mode of reckoning would occasion, must have been too obvious not to have been noted. For, supposing it to have been settled, at any particular time, that the beginning of the year should be in the spring; in about sixteen years afterwards, the beginning would have been in autumn; and in thirty-three, or thirty-four years, it would have gone backwards, through all the seasons, to spring again. This defect, however, they attempted to rectify, by introducing a number of days at certain times into the calendar, as occasion required, and putting the beginning of the year forwards, in order to make it agree with the course of the sun. But as these intercalations were generally consigned to the care of the priests, who, from motives of interest or superstition, frequently omitted them, the year was made long or short at pleasure, and the calendar was yet in a very imperfect state.

Several methods of correcting these errors, had been frequently proposed to the Roman senate, by the mathematicians of those times; but that people, intent only upon the aggrandizement of their empire, and extending the terror of their arms, had no leisure for the peaceful pursuits of science, and were long ere they aspired to the glory of being learned and enlightened. Julius Cæsar was the first among them, who, to his other extraordinary qualities, added an eminent knowledge of the sciences of astronomy and mathematics.

> "Amidst the hurry of tumultuous war,
> The stars, the gods, the heav'ns, were still his care;
> Nor did his skill to fix the rolling year,
> Inferior to Eudoxus' art appear."
>
> LUCAN.

The state of the calendar particularly engrossed his attention, and being convinced of its irregularity, he was immediately determined to reform it. To assist him in this undertaking, he made choice of Sosigenes, a celebrated mathematician of Alexandria in Egypt; who found, that the dispensation of time could never be settled upon any sure footing, without having regard to the annual revolution of the sun; and as this revolution is found to be completed in three hundred and sixty-five days, and about six hours, he made the year to consist of three hundred and sixty-five days, for three years successively, and every fourth year of three hundred and sixty-six, in order to take in the odd six hours.

This reformation was made in the year of Rome 708, about forty-five years before the birth of Christ; and as it was computed that near ninety days had been lost by the former method of reckoning, these were now taken into the account, and the first Julian year was made to consist of four hundred and forty-four days; which was, therefore, called Annus Confusionis, the year of confusion. After this, the beginning of the year was fixed to the first of January, and each of the months, except February, were divided into thirty, or thirty-one days, as they are at present; the reason of which distribution, seems to have been a desire of preserving, as much as possible, an equality among the months; and to make them nearly agree with the lunar months, which consist of about twenty-nine days and a half. The odd day, which arises out of the six hours above-mentioned, was introduced into the calendar every fourth year, by reckoning the twenty-fourth of February twice over; and as this day, in the old account, was the same as the sixth of the calends of March, which had been long celebrated on account of the expulsion of Tarquin, it was called, *bis Sextas ca* *lendas Martii*; from which we have derived our name of Bissextile, or Leap-year.

Julius Cæsar was born upon the fourth of the ides of the month Quintilis, and after his death, Marc Antony, who was one of the Triumvirate, ordained that the name of this month should be changed to that of Julius, in honour of his predecessor. The name of the month Sextilis was also changed to that of Augustus, in memory of the emperor of that name; and these appellations have been retained ever since. But Nero, who had given his name to the month April, and Domitian, who had given his to the month October, were soon deprived of these honours; for after the death of those tyrants, their names were taken from the calendar, and the former ones reinstated.

The Julian account, as this method of reckoning has since been called, though far superior to any that preceded it, was, however, still imperfect: for as the time in which the sun performs his annual revolution, is not exaotly three hundred and sixty-five days, six hours, but three hundred and sixty-five days, five hours, forty-eight minutes and fifty-one seconds and a half, the civil year must, therefore, have exceeded the solar year by eleven minutes, eight seconds and a half; which, in the space of about one hundred and thirty years, amounted to a whole day: and, consequently, in forty-seven thousand four hundred and fifty years, the beginning of the year would have advanced forwards through all the seasons; so that in half this space of time the summer solstice, according to the calendar, would have fallen in the midst of winter, and the earth been covered with frost, when the bloom of vegetation was expected.

It is not to be imagined, that Sosigenes was totally unacquainted with this error; but he probably thought it much smaller than it really is, and on that account neglected it. The true length of the solar year had not yet been accurately determined; and as it was only from a sensible anticipation of the seasons, that the civil reckoning could appear defective, the Julian account was long considered as perfectly consonant with the course of nature; and all the states of Europe confided in it, as one of the most exact and just estimations of time that could be devised. Some irregularities were occasioned, soon after the death of Cæsar, by the negligence of the pontiffs, who had not observed the established method of intercalating the odd day; but from the time of Augustus, who corrected these errors, to about the middle of the sixteenth century, it does not appear that the calendar had been subject to any alteration.

Among the first of those who discovered its imperfections, were our countrymen the venerable Bede, Sacro Bosco, and Roger Bacon. Those great men, who were the ornaments of the times in which they lived, had observed that the true equinox preceded the civil one, by about a day in a hundred and thirty years. And as the council of Nice, which was held in the year 325, had fixed the vernal equinox to the twenty-first of March, it was accordingly found, that from that time to the year 1582, when the next reformation was effected, the error occasioned by this means, amounted to about ten days; so that the vernal equinox was now found to happen on the eleventh of March, instead of the twenty-first, as it ought to have done, had the Julian account agreed with the course of the sun.

This constant anticipation of the equinox, which in the course of more than a thousand years, had become too obvious not to be noticed, was first represented to the councils of Constance and Latran, by two cardinals, Ailli and Cusa, who showed the cause of the error, and the means of correcting it. And in the year 1474, Pope Sixtus IV. being convinced of the necessity of a reformation, sent for Regiomontanus, a celebrated mathematician of that time, to Rome, and presented him to the archbishoprick of Ratisbone, in order to engage him in this undertaking; but as a premature death prevented his assistance, the project was, for that time, suspended.

The necessity of some alteration was, however, still insisted upon: and about a hundred years afterwards, Pope Gregory XIII. had the honour of accomplishing what several preceding pontiffs and councils had attempted in vain. A plan, which was presented to him by Aloisius Luilius, a Veronese physician and astronomer, after being examined by the most able mathematicians of that time, was sent to all the princes in Christendom, for their advice and assistance; and as the execution of it appeared to be attended with little difficulty, it met with general approbation. A council, therefore, of the most learned prelates, was convened by the pope, and the subject being finally settled, a brief was published in the month of March, 1582, by which the use of the ancient calendar was entirely abrogated, and the new one substituted in its stead.

This was called the Gregorian account, or New-Style; and as it is that which is at present in use throughout the greatest part of Europe, I shall endeavour to give you as familiar an account of it as possible. The first object of the reformers, was to correct the errors of the former method of reckoning, and to make the length of the year agree more exactly with the course of the sun. For this purpose it was agreed, that the ten days, which had been gained by the old account, should be taken from the month of October, of the year then current, and the equinox brought back to the twenty-first of March, as it had been settled by the Nicene council. And, that a like variation might not happen in future, it was ordered, that instead of making every hundredth year a bissextile, as it was in the former method, every four hundredth year only should be considered as a bissextile, and the rest of the even centuries be reckoned as common years.

The length of the solar year, and the time of the vernal equinox, were by this means very accurately settled; for as a day was gained, by the former method of reckoning, in every hundred and thirty years, this was nearly equivalent to a gain of three days in every four hundred years; and consequently, by making the years 1700, 1800, and 1900, to be common years instead of Leap-years, as they would otherwise have been, the error arising from the odd time would be properly corrected. But this was a part of the subject that was easily accomplished; the great difficulty consisted in making the lunar year agree with the solar one, and in settling the true time for the observance of Easter, and other moveable feasts, which had hitherto been subject to no regular rule.

It was ordered by the council of Nice, that Easter should be celebrated upon the first Sunday, after the first full moon, next following the vernal equinox. And in order that this rule might be properly observed, it became necessary to know the days when the full moons would happen, in the course of every year. But this was a knowledge that was not easily obtained; for the period formerly established by Meton, a celebrated Greek philosopher and mathematician, which made nineteen years exactly equal to two hundred and thirty-five lunations, or revolutions of the moon, was found to be too long by about one hour and thirty-two minutes: and, consequently, after sixteen of these periods, the true phases of the moon would precede those shown by the calendar, by more than a whole day.

At the time when the Gregorian account first took place, the error occasioned by this means amounted to about four days; and had the old method of computation prevailed, the calendar, in time, would have announced the full moon at the time of the change, and Easter would have been celebrated at a period directly opposite to that established by the church. To correct these errors, therefore, it was necessary that some other method should be devised, than that which had been hitherto in use; and as the old lunar cycle of nineteen years had a particular property, which had not yet been noticed, Luilius had the good fortune to discover it, and to make it subservient to the purposes required.

The new and full moons, which according to Meton, were imagined to happen at exactly the same time as they had nineteen years before, were usually indicated in the following manner; it was observed on what day of each calendar month the new moon fell, in each year of this period, and against those days they placed the number answering to that year, reckoning from one to nineteen, through all the years of the cycle. And those numbers, on account of their great usefulness, were called Primes, or Golden Numbers; but as Luilius found them to be erroneous and inconvenient, he rejected them, and made use of others, called Epacts, in their stead.

The epact, is the difference between the solar year and the lunar one; or, which is the same, it is the moon's age at the end of the year. But, in order that this may be better understood, I shall illustrate it by an example. Suppose, therefore, that at any particular time, the new moon was to happen on the first of January, the epact for that year would then be nothing. And as twelve lunations are completed in three hundred and fifty-four days, it is plain, that the epact, or moon's age, at the beginning of the second year, would be eleven; at the beginning of the third year, twenty-two; and at the beginning of the fourth, thirty-three. But as the time of one lunation is never more than twenty-nine days and a half, the epact cannot possibly exceed thirty; in this case, therefore, thirty must be subtracted; so that instead of thirty-three, at the beginning of the fourth year, the epact will be only three. And by observing this rule, through a period of nineteen years, the epacts will stand in the following order, 0, 11, 22, 3, 14, 25, 6, 17, 28, 9, 20, 1, 12, 23, 4, 15, 26, 7, 18.

These epacts being placed against the days of the month in the calendar, on which the new moons fell in each year, would have answered the same purpose as the golden numbers; and had the Metonic cycle been complete, the form would have required no alteration: but this is not the case; for after about sixteen of these periods, or three hundred years, the new moons, arriving sooner by twenty-four hours, would happen on the preceding day; and therefore the epacts answering to those new moons, ought to be augmented by unity. For supposing that the second year of the lunar cycle had eleven for the epact, then because the new moon, in the preceding year, arrived eleven days before the end of December, after three hundred years, the same new moon, of the first year of the cycle, would arrive twelve days before the end of the year; and consequently the second year ought now to have twelve for the epact.

This number twelve, therefore, will be the index of the new moons in that second year; and it is easy to perceive, that all the new moons which happen sooner by a day, will take place upon the day preceding that which, in the former period, was marked eleven. After three hundred years more, the epact will be thirteen, which will be a day still preceding that in the latter period: and the same will happen with all the other epacts of the cycle. It was this kind of analysis, that gave Luilius the idea of placing the epacts in their natural order, against the days of the new moons in every year, for the first three hundred years; and after that period, to place them in the order 1, 12, 23, 4, 15, 26, 7, 18, 29, 10, &c. instead of the former one: and so on.

This arrangement was simple and ingenious; but the omission of three days in every four hundred years, was a circumstance that occasioned some embarrassment. These years, having a day less than in the Julian account, the new moons would happen a day later, and consequently the epact, at the end of the year, must be diminished accordingly. But as this order is only interrupted once in a hundred years, Luilius imagined, that by subtracting unity from each of the epacts belonging to those new moons, they might be made to serve for the subsequent century. And as there are only thirty possible series of these numbers, it was sufficient to show by a table, what series belonged to every century; by which the times of the new moons might be readily discovered.

This is a concise account of the Gregorian reformation; and if you are desirous of further information, I must refer you to works written expressly upon the subject; for to have given a minute detail of every particular, would have required a large volume. If what has been said, however, be properly attended to, it will enable you to form a general idea of this intricate business; which, as the matter is now fully settled, is all that is requisite. It only remains just to mention, what reception this alteration of the style met with, from the different states of Europe.

Pope Gregory ordered all the ecclesiastics under his jurisdiction to conform to this new method of reckoning, and exhorted the Christian princes to adopt it in their dominions. But the protestant states, at that time, refused it; the reformed religion being in its infancy, the zeal of its professors was violent, and their opposition to the pope unbounded: whatever bore the appearance of his authority, was rejected as an unwarrantable encroachment upon their newly-acquired liberties; and though the propriety of the alteration was acknowledged, it was condemned on account of its orginating with a party so extremely obnoxious to them.

But the difference between the old and new style, as the Julian and Gregorian accounts are generally called, occasioned great confusion in the commercial affairs of the different states of Europe. In England, particularly, this inconvenience was considerably felt, and several attempts were accordingly made to introduce the reformed calendar; but popular prejudices were too strong to be easily overcome. The mathematicians, indeed, more influenced by scientific considerations than cavils about points of religion, were continually urging the necessity of some correction, and proposed several methods of obtaining it, which might be adopted without inflaming the minds of the multitude.

One of the most simple and ingenious of these, I shall just mention; which was, that an act should be passed, declaring that there should be no leap-year for forty years to come; by which means, the ten days, that had been gained by the old account, would have been imperceptibly lost, and the old style reduced to the new, without any sensible variation in the fixed time of feasts, and other observances. A proposal of this kind was sent to Dr. Wallis, then professor of Geometry at Oxford, for his opinion: but the doctor, with a narrowness of sentiment, which could scarcely have been expected from a man of his extensive erudition, observed, that the proposal was specious enough in appearance, but that the hand of Joab might be perceived in it. He imagined it to have originated with the papists; and though he acknowledged its propriety, was yet afraid of its being adopted, lest it should open the door to further encroachments.

But though all proposals were at that time rejected, yet those who wished for a reformation, still continued their applications; and in 1752, an act of parliament, after much debate, was obtained for this purpose. And as a hundred and seventy years had elapsed since the Gregorian alteration took place, the old style had consequently gained above a day more upon the course of the sun than it had at that time; it was therefore enacted, that instead of cancelling ten days, as had been done by the Pope, eleven days should be left out of the month of September; and, accordingly, on the second of that month, the old style ceased, and the next day, instead of being the third, was called the fourteenth.

It may be observed, however, that the Gregorian reformation met with many opponents from men of science; Mæstlin, Scaliger, Vieta, and other mathematicians, attacked it with great violence, and proposed methods of their own, which they considered as less exceptionable. But Clavius, to whom the care of this business was assigned, after the death of Luilius, composed a large work in its vindication, and victoriously combated all his adversaries. Some defects, however, it must be acknowledged, are to be found in this method; but the task of reformation was difficult; the reformers had to choose among a number of inconveniences, and they appear to have preferred the least considerable; we ought, therefore, to applaud them for their skill, rather than censure them for defects which no human abilities could have wholly avoided.

LETTER XV.

OF THE MENSURATION OF THE EARTH.

To measure the earth, and thence to determine its magnitude and figure, is one of the most astonishing enterprises, that ever was undertaken by man. Confined to a particular spot, without any other scale or model than his own proper dimensions, how is he to find the distances of places which he can never visit, and to embrace the vast circumference of the globe? The space he has passed through, may be estimated by the number of steps he has taken, and this will furnish him with some of the most simple measures, the foot and the yard; the cubit is also the length of his arm, from the elbow to the end of the middle finger; and the fathom, or toise, is the distance he can reach with his two arms extended; but what are these small measures in comparison to the perimeter of the earth? They are but as a grain of sand to the largest mountain. Difficulties, however, serve but as incitements to action; and man, instead of being confounded by the inadequacy of his natural powers, finds a resource in his intelligence which supplies their defect: he multiplies small measures, till he arrives at the greatest, and forms to himself an unit, to which he refers all the parts of the universe.

By means of chains and cords, which are certain multiples of the toise, or the yard, he obtains an artificial measure more convenient than the natural one; and with this new standard, repeated a certain number of times, in the same manner as before, he forms furlongs, miles, and leagues, and undertakes to measure such distances, as would be otherwise indeterminable. But this method is yet totally inadequate to the purpose required; for if it were necessary to trace the whole circumference of the earth, in order to obtain its measure, the thing would be impossible; mountains, rivers, and seas would be perpetual obstacles in our way; and uninhabitable climates would put an entire stop to our progress. In order, therefore, to surmount these difficulties, we must have recourse to Astronomy, which furnishes us with a method of measuring the circumference of the whole terraqueous globe, by only ascertaining the length of a small arc of one of its great circles.

But let us leave this part of the subject for the present, and attend to the steps which led to so important a discovery. It was the commonly received opinion, even so late as the fifteenth century, that the earth was a flat body, indefinitely extended, and covered by the sky, in the form of a vault or tent. And as this doctrine had received the sanction of some of the most respectable Fathers of the Church, and was thought to be founded on the authority of the Bible, but few, even among philosophers themselves, presumed to question its validity. But a very little time before the discovery of America, the notion of the earth's having a globular form, was treated as an impious absurdity. At length, however, reason, and the voyage of Christopher Columbus, restored to the earth its spherical figure, which the ancient Egyptians and Chaldeans had given it; and it was now generally believed to be a perfect globe, and that the stars made their revolutions round it in circular orbits.

Of this opinion were the greatest philosophers of the age. A globe is the most perfect of all geometrical figures; and the observed simplicity of nature, in most of her operations, seemed to favour the idea of the earth's having such a form. This imaginary simplicity, however, proved to be a false light, which misled its followers. M. Richer, in a voyage made to Cayenne, near the equator, undertaken by order of Louis XIV., under the protection of the great Colbert, among many other observations, found that the pendulum of his clock no longer made its vibrations so frequently as in the latitude of Paris; and that it was absolutely necessary to shorten it by a line and a quarter, or a little more than the eleventh part of a Paris inch, in order to make it agree with the times of the stars passing the meridian.

Natural philosophy and geometry were not then by far so much cultivated as they are at present; and who could have believed, as a celebrated writer has remarked, that from an observation so trifling in appearance, could have sprung so sublime and philosophic a truth. A pendulum, like any other falling body, is acted upon by the force of gravity; and, in consequence of Richer's discovery, it was observed, that, since the gravity of bodies is by so much the less powerful as those bodies are farther removed from the centre of the earth, the region of the equator must absolutely be considerably more elevated than that of France; and that, therefore, the figure of the earth could not be that of a sphere.

This reasoning, so very simple and natural, escaped, however, some of the greatest philosophers of that time; a certain proof that the strength of prejudice does not permit the slightest examination: they even contested Richer's experiment. Metals are known to be lengthened by heat, and contracted by cold, and to this cause they attributed the difference which he had observed between the vibrations at Cayenne and at Paris. The most intense summer heat will lengthen an iron rod of thirty feet long, about the eleventh part of an inch; but the question here was concerning an alteration, which was afterwards found to be nearly twice as great as this, in a rod of little more than three feet in length; and, therefore, this dilatation must have been owing to some other cause than that of heat.

Some years after this, Messrs. Deshayes and Varin, who were sent out by the French king, to make certain astronomical observations near the equator, found that the pendulum at Cayenne, required to be shortened much more considerably than had been mentioned by Richer. He had observed, that it made a hundred and forty-eight vibrations less in a day than at Paris, and that his clock was retarded, by that means, two minutes and twenty-eight seconds; but M. Deshayes found a much larger difference, and was obliged to make his pendulum shorter by two lines, in order to make the time agree with that which was deduced from celestial observations. This difference between the two observers may be easily accounted for; Richer was struck with the singularity of the phænomenon, and, as is natural upon such occasions, examined it with timidity. He doubted whether his senses might not have deceived him, and endeavoured to see the least variation possible.

The truth of the experiment, however, has been since fully confirmed by the French academicians, in the account which they have given of their expedition to Peru, in South America. They inform us that about Quito, at a time when it froze, they were obliged to shorten the pendulum for seconds about two lines, or the sixth part of an inch; which puts it out of all doubt, that the alteration could not be occasioned by heat. The same phænomenon has likewise been observed at Martinique, at St. Domingo, at St. Helena, and at Goree, upon the coast of Africa, near the Cape de Verd islands; in all which places it was found, that the alteration was the greater the nearer they were to the equator, and that it diminished as the observer approached towards the northern climates.

The observations made at Cayenne, might have been considered as too local and particular to have admitted of any satisfactory conclusion; but as a like alteration was found to take place in so many different situations, we can no longer hesitate in receiving it as a general phænomenon, arising from an actual diminution of gravity, in those places where the experiment was performed. This discovery, trifling as it may seem, opened a new field of speculation to philosophical minds; and there are, perhaps, few facts, in the whole circle of the sciences, from which so many curious and useful consequences have been derived. Some of the greatest mysteries in nature began now to be unveiled: the philosopher extended his enquiries, and the mathematician demonstrated truths as sublime and important, as they were new and surprising.

Those great men, Newton and Huygens, were the first who perceived the extensive application of which this discovery was capable. They seized the new truth with avidity; and, by following it through all its consequences, obtained the solution of a problem, which seemed beyond the reach of human abilities. This was no less than the determination of the true figure of the earth, which they discovered from mathematical considerations only; and notwithstanding all the light that has been since thrown upon this subject, both from an actual mensuration of the earth, and from the laborious researches of some of the first philosophers in Europe, the measure of Newton is generally considered as very accurate, and is still frequently used, in preference to all others.

To enter into all the calculations that were employed in this enquiry, would be foreign to my purpose. I shall only give you an account of the principles upon which they were founded, and leave the rest as a subject for your more mature consideration and reflection. It is a known property of the pendulum, that, in small arcs, all its vibrations made in the same place are performed in the same time; and that the time in which each vibration is performed, is in proportion to the square root of the length of the rod: thus in the latitude of London, a pendulum of thirty-nine inches and an eighth in length, makes its vibrations in a second; and one of nine inches and three-quarters, makes its vibrations in half a second; so that the shorter the pendulum, the swifter it moves; and the longer it is, the slower it moves; the ratio being always the same as that before-mentioned.

But the time in which any pendulum performs its oscillations, depends not only upon the length of that pendulum, but also upon the intensity of the force which impels it towards the surface of the earth. If this force be diminished, by any cause whatever, the body, having a less tendency to motion, will employ a longer time to move through the same space; and, therefore, in order that each vibration may be made in the same time as it was before, the length of the rod must be shortened; by which a new velocity may be given to it that will be sufficient to supply the defect in point of gravity. This was exactly the case, in the experiments made at Cayenne, and other places near the equator; the observers were obliged to shorten the rods of their pendulums, in order to make them perform their vibrations in the same time as at Paris; and from this it was properly inferred, that gravity, or the force that occasions their descent, had actually suffered a real diminution.(*n*)

But by what cause is it, that gravity is less powerful under the equator, than at London or Paris? This is the question, upon which every thing relating to the subject in question depends. Sir Isaac Newton considered it in the following manner. The diurnal rotation of the earth is performed round an imaginary line, which passes through the two poles; and as the equator is farther distant from its centre, than any other circle which is parallel to it, it is plain, that those parts

(*n*) The following Table exhibits, at one view, the proportional lengths of a seconds pendulum, as deduced from observations made in different latitudes, between the equator and the pole; that of Paris being taken as unity.

Places.	Latitudes.		Lengths.
Peru	0°	00′	0·99669
Porto Bello	9	33	0·99689
Pondicherry	11	55	0·99710
Jamaica	18	00	0·99745
Petit Goare	18	27	0·99749
Cape of Good Hope	35	55	0·99877
Toulouse	43	35¾	0·99950
Vienna	48	12¾	0·99987
Paris	48	50	1·00000
Gotha	50	58	1·00006
London	51	30	1·00018
Petersburg	58	15	1·00074
Ponoi	59	56¼	1·00101
Avengsberg	66	47¾	1·00137
Pello	67	4½	1·00148

of the earth which lie under the equator, will move with a greater velocity than those which are nearer to the poles; and of course, the equatorial regions will become more elevated than the polar ones; so that if the earth were an entire fluid, and the waters met with no obstacles in their progress, they would recede from the poles towards the equator, and by that means flow in continually till they had formed an equilibrium, and could rise no higher.

This tendency of bodies to fly off from the centre round which they move, is called the centrifugal force, the nature and existence of which, may be made evident in a number of ways. When a mop is turned upon the arm, by a quick circular motion, the threads, or thrumbs, are observed to rise highest in the middle; and the swifter the mop is whirled, the greater will be the force, and the particles will fly off with the greater velocity. The same thing is observable, when a stone is turned swiftly round, by means of a sling; the arm finds itself stretched by a considerable force, which force is exerted upon it by the stone, in its endeavours to recede from the centre; and if the stone be disengaged from the sling, by a sudden stop of the hand, it will immediately manifest the tendency which it has to leave this constrained circular orbit, by its proceeding directly forwards in a straight line.

Besides this, there is another force, which is called centripetal; being so denominated, because it is directed towards the centre, and acts in direct opposition to the former. This force, in the present case, is the same as gravity; the nature of which may be thus explained. All heavy bodies, when left to themselves, are observed to fall towards the earth in straight lines, which are perpendicular to the horizon; and if those lines were continued, it is plain, from the nature of a globe, that they would all pass through the earth's centre. Every part of the earth, therefore, gravitates towards the centre; and as this force is found to be about two hundred and eighty-nine times greater than the opposite one, or that which arises from the rotation of the earth upon its axis, a certain balance will constantly be maintained between them, and the earth will assume such a figure as would naturally result from the difference of these two contrary and opposite forces.

Biot, in his Astronomy, illustrates this effect in the following manner. Let us consider two fluid columns communicating with each other, the one being placed in the plane of the equator, and the other in the direction of the poles, and each extending from the centre to the surface of the earth. Now the particles which are found in the column at the equator will have a tendency, from the centrifugal force, to fly off from the axis of rotation, and therefore their weight, or tendency towards the centre, will be a little diminished. The column of the poles on the contrary, having no centrifugal force, will obey the law of gravity only, which draws it towards the centre of the two columns. This is therefore really heavier than the other column, and consequently an equilibrium cannot take place between them, till the decrease in gravity is compensated by an increase in length in the equatorial column. And a similar effect must necessarily be produced in every column parallel to the equator; but it becomes less and less as the centrifugal force diminishes; that is, as we approach nearer and nearer to the poles; and hence it is obvious, that the equatorial regions of the earth ought to be the most elevated, and that this elevation ought to diminish by insensible degrees from the equator to the pole.

But as this illustration depends entirely upon a mental conception of the subject, I will endeavour to put it in another point of view, which will probably be more convincing. For this purpose, let AB, (Plate VIII. fig. 1.) represent a beam supported upon a fulcrum C, in such a manner as to admit of being whirled round in an horizontal direction. And let D and E be two heavy balls, suspended from its extremities A and B; which, while the beam remains at rest, will hang in the perpendicular directions AD and BE. But if the beam be made to revolve about its centre C, the balls will fly off from their perpendicular direction, at a less or greater angle according to the velocity of the beam, and will come into the directions A*d* and B*e*. And if now two other balls, as F and G, (Fig. 2.) be suspended at the equal distances CK and CL, these will also fly off in the directions K*f* and L*g*, making a less or greater angle with the perpendiculars KF and LG, according as they are nearer to, or more remote from, the fulcrum C.

If now, in order to apply this to the figure of the earth, we change the beam AB (Fig. 3.) for a semi-circular plane AMB, which is free to revolve about CM as an axis, and suspend from different points of its circumference A, K, L, M, &c. the same heavy balls by lines of equal length; they will, while the plane remains at rest, form themselves into a semicircle D, F, G, E. But if now the planes C*m*, B*b* be made to revolve about CM, they will fly off from their perpendicular, into the direction shown by the dotted lines in the figure; those at A and B making the greatest angle with their perpendiculars, and the angles of the other diminishing as they are nearer the centre of motion, as we have seen in fig. 2 above. And therefore, the curve passing through the several balls in their present positions at *d*, *f*, *i*, *m*, &c., will not be a circle but an ellipse; the longest diameteter of which will be *de*, and the shortest semi-diameter M*m*; the former of which will represent the equitorial, and the latter the polar axis of the earth; the difference of which will be greater or less, according as this body revolves with a greater or less velocity.

It was by means of the results which I have mentioned above, of the difference in the times of vibrations of pendulums, in different latitudes, that Newton founded his sublime calculations upon this interesting subject; and, as Fontenelle observes, determined the true figure of the earth without quitting his elbow-clair. The experiments of Richer, at Cayenne, first attracted his attention; and by applying himself to the subject, he soon perceived the reason of all the phænomena which that gentleman had discovered. As gravity is the same upon all parts of the earth, and the centrifugal force is greatest at the equator, it is plain that the action of such a force must diminish the weight of bodies, and occasion them to fall with a less degree of velocity at the equator, than at places nearer to the poles.

Newton and Huygens were both engaged in these enquiries at the same time, and the results of their calculations were nearly alike: they each of them separately considered, that this diminution of gravity, which manifests itself in such bodies as are detached from the earth, and left to themselves, must also have the same influence on the constituent parts of the earth, which, by their mutual coherence, compose the solid mass of the globe. From this obvious principle, which is agreeable to universal experience, it was discovered, that the centrifugal force at the equator, is about a two hundred and eighty-ninth part of the force of gravity; or, which is the same thing, that a body weighing two hundred and eighty-nine pounds at the pole, would weigh only two hundred and eighty-eight at the equator.

It has been estimated, that about two-thirds of the surface of the earth are covered by the ocean; and as it is the nature of fluids, for their particles to be easily moved among themselves, they will yield and give way to the slightest impression. That diminution of weight, therefore, which arises from the action of the centrifugal force, will readily manifest itself in all fluids; and as it has been shown, that gravity acts less powerfully at the equator than at the poles, the waters will of course flow towards the equatorial regions, in order to balance those at the poles. But this elevation is not confined to the waters of the ocean; the solid parts of the globe must also be subject to the same force; for if the lands which lie under the equator were not elevated in the same proportion with the waters, the ocean, leaving its bed, would submerge the continent, and the greater part of the torrid zone would be one continued sea.

This revolution, however, has not taken place. The East and West Indies, and a great part of the vast continents of Africa and America, lie in the neighbourhood of the equator, and are sufficient proofs, that the earth, in those regions, rises to defend itself against the invasions of the ocean. Every part of the globe, therefore, from the centre to the circumference, is subject to the action of a centrifugal force; and supposing the primitive figure of the earth to have been that of a globe, which is the shape it would naturally assume from the mutual attraction of its constituent parts, this force, or the action arising from a constant rotation upon its axis, would evidently change it into an oblate spheroid, or a body formed by the motion of a semi-ellipsis, revolving round its conjugate axis. This was the figure determined by Newton, who found, by mathematical calculations, that the polar diameter of the earth is to the equatorial, as two hundred and twenty-nine is to two hundred and thirty; or, that the regions of the equator are elevated about thirty-five miles more than those at the poles.

Who could have imagined, that such a simple circumstance as the retardation of clocks in certain climates, and the necessary shortening of the pendulum, would have given birth to such a grand and important discovery, as that of the true figure of the earth! But such is the wonderful connection and secret dependence of things: nature is uniform in all her operations, and it is her peculiar excellence, that she often produces the greatest effects from the most apparently trivial causes. To discover this hidden correspondence, is the privilege only of superior minds; and such is the ignorance and envy of the multitude, that the man who first announces these truths to the world, is often considered as no other than a troublesome promulgator of doubtful doctrines, which serve only to disturb the peace and happiness of mankind. Newton, the great founder of modern philosophy, was more happily circumstanced; he had the good fortune to live in an enlightened age, when bigotry and superstition were every day losing ground: his genius set him at such a height above the rest of mankind, that common minds shrunk from his enquiries, and but few, even among the learned, were proper judges of his merit. "Il a fallu (says Mons. Bailly) du tems et de longues études pour comprendre Newton, et se rendre digne de recevoir ses leçons."

The figure of the earth, however, is a mathematical truth, which is confirmed by analogy; for by means of a good telescope, it is easy to perceive, that the planet Jupiter is flattened about his poles, in nearly the same manner as has been asserted of our earth. What exists in one planet, therefore, is possible in another; and as it appears highly probable that matter is every where endowed with similar properties, it is natural to infer that the same force which has compressed the globe of Jupiter, has also occasioned a like alteration in our earth. Jupiter is composed of a heavy matter, which is capable of attracting his satellites in the same manner as our earth attracts the moon; but as his rotation upon his axis is performed with a greater rapidity than that of the earth, so the alteration in his figure is found to be much more considerable, as would naturally follow from such a motion. The relation of his diameters, according to Newton, is nearly as twelve to thirteen, and the difference between his equatorial and polar diameters is about six thousand two hundred and thirty miles.

LETTER XVI.

THE SAME SUBJECT CONTINUED.

Let us now quit the researches of Newton, and see how far his mathematical deductions have been confirmed by experience. This is the true test of all hypothetical reasoning, and is what he himself lays down as the basis of every philosophical enquiry. The great utility and importance of this interesting subject was far from being unknown to the ancients. We are assured from the testimony of Herodotus, and other early historians, that attempts had been made to discover the true figure of the earth, by many of the most celebrated mathematicians of antiquity: Ptolemy, in his Almagest, has preserved the measures of Hipparchus, Eratosthenes and Posidonius, who all lived before the time of Christ; and from what M. Bailly has advanced in his Histoire de l'Astronomie Moderne, it appears highly probable, that this singular enterprise had been undertaken in the still more remote ages of the world.

But as all the determinations of the ancients are uncertain, on account of our being unacquainted with the length of their stadium, or principal measure, I shall pass over the peculiar methods and operations they employed, and proceed to those of the moderns, which are far more accurate and scientific. Riccioli attempted to measure the earth according to a method mentioned by Kepler. It was known from observation, that heavy bodies, in falling, tend towards the centre of the earth. And as the distance of any two places upon the surface of the earth may be considered as the base of a triangle, whose vertex is at the centre, he measured a large base of this kind, in the most accurate manner possible, and found the angles which it made with a plumb line at each of its extremities. The sum of these angles, by a property in geometry, being taken from a hundred and eighty degrees, gave him the angle at the vertex; and as he had now obtained the measure of an angle at the centre of the earth, and the length of a corresponding arc upon its surface, it was easy, by the rule of proportion, to find the length of the whole circumference. For, by the property of the circle, as the degrees in this angle are to three hundred and sixty degrees, so is the length of the base to the circumference required.

This method of Riccioli, however, is more ingenious than accurate; he wanted to measure the earth, without having recourse to celestial observations; but the independence to which he aspired was not to be obtained. Order and regularity are only to be found in the heavens; and it is to them we are indebted for almost all we know of the earth. We are deceived by every thing around us; even our senses mislead us; and what we think ourselves the best acquainted with, frequently proves to be an illusion. Objects seen at a distance never appear in their true places; they are always more or less elevated, according to the season, and the hour of the day; and on this account, it is not easy to determine either their true height, their direction, or the angle at the centre, which depends upon this direction. By not attending to these particulars, Riccioli was mistaken near six thousand toises in the length of a degree.

The next who attempted to determine the circumference of the earth was Snellius, a German. He measured the distance between Alcmaer and Bergen-op-zoom; and by taking the celestial arc, which corresponds to this distance, with proper instruments, he found the length of a degree to be fifty-five thousand and twenty-one toises. But the person who engaged in this enterprise with the most success, was our countryman Mr. Richard Norwood. In the year 1635, he took the sun's altitude, when it was in the summer solstice, both at London and York, with a sextant of five feet radius, and by that means found the difference of latitude between these two cities to be two degrees and twenty-eight minutes. He then measured their distance, in the usual manner; and having taken into the account all the turnings and windings in the road, with the ascents and descents, he reduced it to an arc of the meridian, and found it to contain twelve thousand eight hundred and forty-nine chains; which distance, being compared with the difference of latitude, gave him five thousand two hundred and nine chains to a degree, or about sixty-five English miles.

This method will want no explanation, if the two places be considered as lying under the same meridian, which indeed is nearly the case; for then the terrestrial and celestial arcs will exactly correspond with each other, and the relation of either of them to the whole circumference will be readily found. The same thing may also be easily performed, by trigonometry, when the two places lie under different meridians; for if we measure the distance of any two objects, and take the angles which each of them make with a third, the triangle, formed by the three objects, will become known; so that the other two sides may be as accurately determined by calculation, as if they had been actually measured in the same manner as the first. And by making either of these sides the base of a new triangle, the distances of other objects may be found by trigonometry as before; and thus, by a series of triangles, connected together at their bases, we might measure the whole circumference of the earth. But this would be an enterprise as useless as it is laborious: for since we know the relation which any part of a circle bears to the entire circumference, the measure of a few degrees, or even of one single degree, will be sufficient to give the measure of the whole.

All the measures, however, that had been hitherto taken were subject to many inaccuracies, on account of the little attention that was then paid to the niceties of instrumental observations. The means of precision, which have since been found so necessary to an exact investigation of this delicate subject, were then wanting; and without them, it was impossible for either genius or industry to avoid considerable errors. By applying the telescope to the quadrant, and furnishing it with a micrometer, we are able to direct it with more certainty to the object, and to find the measures of angles with far greater exactness than could have been done by those who were unacquainted with these admirable inventions.

The Academy of Sciences at Paris, perceiving, from these considerations, the necessity of a new measure of the earth, represented the execution of it as a matter of national honour and importance. All the states of Europe were now enjoying the blessings of a profound peace; and in this interval of happiness and repose, when the voice of genius could be heard, and the talents of individuals united, and directed to one object, the Academy, with a zeal not always to be found in large bodies of men, were unanimously disposed to encourage and assist in the undertaking. This was a moment favourable to the sciences; both the king and his ministers were men of liberal and enlarged minds; improvements were constantly made in every branch of useful knowledge, and genius had something more than empty praise, as a reward for its labour.

M. Picard was the person employed to perform this important business. He began by measuring the distance between Villejuif and Juvisy; (Pl. IX. fig. 3.) and this base, which he found to be five thousand six hundred and sixty-three toises, was the one to which he referred all his calculations. He next placed himself at Juvisy, and by directing the telescopic sights of his quadrant, the one to the wind-mill at Villejuif, and the other to the spire of the church at Brie, he measured the angle subtended by these two objects. Leaving his present station, he removed himself to Villejuif, and, by measuring the angle between Juvisy and Brie, the distance between Villejuif and Brie was found, by calculation, to be eleven thousand and twelve toises. Of this distance he made a new base; and by forming a second triangle between Brie, Villejuif and Monthleri, he found the distance, in like manner, between Brie and Monthleri, to be thirteen thousand one hundred and twenty-one toises. He then formed a third triangle between Monthleri, Brie and Monjay; a fourth between Monthleri, Brie and Malvoisine; and a fifth between Monthleri, Monjay and Mareil; and from all these measures, the distance between Mareil and Malvoisine was found to be thirty-one thousand eight hundred and ninety-seven toises.

In like manner, by means of thirteen triangles, he proceeded as far as Sourdon, near Amiens, and found the distance between Sourdon and Malvoisine to be sixty-eight thousand four hundred and thirty toises. But as calculations are no less subject to errors than mechanical operations, Picard, in order to avoid every inaccuracy of this kind, took a new base near Sourdon, and found its length, both from a continuation of his trigonometrical operations, and from an actual measurement; and as these exactly agreed, he could no longer doubt the truth of his former calculations. For as the two bases were separated by so large a distance, it was impossible for them to correspond, but by a perfect exactitude in all the intermediate steps.

This part of his project being finished, he had now got to reduce the distance between Sourdon and Malvoisine to an arc of the meridian. For this purpose, he placed himself at the Observatory at Paris, and found the angle which the sun's centre made with an object in the horizon, at the time of his setting; (Pl. IX. fig. 4.) for instance, with the spire of the church at Monthleri. And as this angle was known from observation, and the sun's motion being sufficiently understood for him to determine the angle which its centre made with the meridian at the time of its setting, it was easy to find the angle which the spire of Monthleri makes with the meridian that passes by the Observatory of Paris. Hence by a frequent repetition of these observations, as he followed the chain of his triangles, he assured himself of the direction of the meridian; and, by that means, was enabled to draw it with more exactness in the chart which contained his operations.

Having obtained this terrestrial distance to so great a degree of accuracy, he had only to find the celestial arc which corresponded with it. This he did by observing the meridian distances of the same star, both from the zenith of Sourdon and Malvoisine, and taking their difference; and as this difference, which he found to be one degree eleven minutes and fifty-seven seconds, answered to a distance of sixty-eight thousand four hundred and thirty toises upon the earth, he concluded, by the rule of proportion, that the length of a degree must be fifty-seven thousand and sixty-four toises. But having connected Amiens to his series of triangles, and finding from this new measure, that a degree would be fifty-seven thousand and fifty-seven toises, he took a mean between the two, and fixed his degree at fifty-seven thousand and sixty toises, or about sixty-nine and a half English miles. All the angles were taken with a quadrant of thirty-eight inches radius, properly furnished with telescopic sights, and the zenith distances of the stars, with a sextant of ten feet radius; so that with these instruments, and the known abilities of the observer, but little doubt could be entertained of the accuracy of his measures.

But in order that this subject might be settled with the utmost precision possible, it was determined by the French king, that the whole arc of the meridian, passing through France, should be measured in the same manner; and this great work, which was undertaken by Picard, De la Hire, and Cassini, was finished by the latter in the year 1718. He divided the meridian of France into two arcs, which were measured separately; the one from Paris to Collioure, had given him fifty-seven thousand and ninety-seven toises to a degree; the other from Paris to Dunkirk, fifty-six thousand nine hundred and sixty; and the whole arc, from Dunkirk to Collioure, fifty-seven thousand and sixty; which was the same as had been before determined by Mr. Picard.

These surveys were all undertaken upon a supposition that the earth was a perfect sphere; but the truth of this doctrine began now to be much controverted. Newton and Huygens had shown, from the known laws of gravitation, that the true figure of the earth was that of an oblate spheroid, flattened at the poles, and protuberant at the equator. Dominique Cassini, on the other hand, depending more upon the accuracy of his measures, than upon deductions drawn from theoretical reasoning, asserted it to be that of a prolate spheroid, flattened at the equator, and protuberant at the poles. To decide this important question, which had now become a national concern, it was ordered by the French king, that a degree should be measured, both at the equator and the polar circle; so that from a comparison of these with that in France, the true figure of the earth might be determined in as exact a manner as possible.

For this purpose, Messieurs Maupertuis, Clairaut, Camus, le Monnier, and Outhier, were sent to the north of Europe, to measure the remotest degree they could reach; and Messieurs Godin, Bouger, and la Condamine, to Peru, in South America, to measure a degree near the Equator. The first of these companies began their operations at Tornea, near the Gulph of Bothnia, on the 8th of July, 1736, and after experiencing a variety of obstacles and inconveniences, arising from the nature of the climate, finished them about the beginning of June, 1737. Maupertuis, soon after their return to France, published an exact and interesting account of all their transactions; the result of which was, that the true length of a degree of the meridian at, or near, the polar circle, is fifty-seven thousand four hundred and twenty-two toises, or one hundred and seven thousand six hundred and sixty-six English feet and a quarter.

The Academicians who were sent to Peru, in South America, had still greater difficulties to encounter than their friends in Lapland, and were a longer time employed in their operations. They set out upon their expedition about a twelvemonth before the former, and did not finish their survey till the year 1741. The province of Quito was the place fixed upon as the properest for their purpose. Here they measured an arc of the meridian, of three degrees seven minutes and one second, and found it to contain one hundred and seventy-six thousand nine hundred and fifty toises; which being reduced to the level of the sea, and properly corrected, the first degree of the meridian, from the equator, was thence found to be equal to fifty-six thousand seven hundred and fifty-three toises, or one hundred and six thousand four hundred and eleven English feet and seven-eighths.

These measures afford a complete demonstration that the earth is flattened at the poles, and protuberant at the equator. For had the figure of it been a globe, as was formerly imagined, a degree of the meridian, in every latitude, would have been found of the same length; and had the figure been that which was given to it by Cassini, a degree at the polar circle would have been found less than a degree at the equator. But as a degree at the equator appears to be about five hundred and seventy-five feet five-eighths less than a degree in France, and about one thousand two hundred and fifty-four feet three-eighths less than a degree at the arctic circle, it is easy to show, that the figure of the earth must be nearly the same as it was assigned by Newton.

Besides this, it may be observed, that several very exact measurements, of the same kind, have since been made in England, France, and other parts of the world, all of which, when taken together, fully confirm the theory here laid down.

LETTER XVII.

OF THE DISTANCES AND MAGNITUDES OF THE SUN, MOON, AND PLANETS.

It was a question, put by Mr. Molineaux to Mr. Locke, whether a blind man, who had been taught to distinguish a globe from a cube by the touch, would be able, if he could be made to see, to tell which was the globe and which the cube, by the use of his sight only. This question he answered in the negative; and, in his celebrated Essay on the Human Understanding, has shown that a person, so circumstanced, could have no dependence whatever upon his newly acquired sense, but would find himself totally unqualified to judge either of the situation and distance of objects, or of their magnitude and figure.

A young man, who had been born blind, had the use of his eyes given to him by Mr. Cheselden, an eminent surgeon of that time, and all the ideas of the youth, on whom this singular operation was performed, were in favour of Mr. Locke's opinions. At the age of about fourteen years, he saw the light for the first time in his life; and was so perplexed and embarrassed with every thing about him, that he scarcely knew what to make of his new situation. For a long time, he could form no judgment of things by the use of that sense alone. An object of an inch in diameter, placed before his eyes, which concealed a house from his sight, appeared to him as large as the house. Whatever he saw, seemed to be upon his eyes, and to touch them, as the objects of the sense of feeling touch the skin.

It was also observed, that what he had judged to be round, by the help of his hands, he could not distinguish from what he had judged to be square; nor could he discern by his eyes, whether what his hands had perceived to be above or below, was really above or below. It was not till after two months experience, that he could tell pictures from solid bodies; he thought bodies, and not surfaces, were in the painted canvas; and when he applied his hand to them, was amazed to find that they vanished from his touch. He was continually asking which of the senses it was that deceived him, that of feeling, or that of seeing. Nor could he understand how it was possible for the house he was in to be larger than his chamber; and even after he had acquired the proper use of his eyes, he was at a loss to conceive how sight had given him that idea.

This was an indisputable decision, that the manner in which we see objects is no immediate consequence of the angles formed in our eyes; for the same angles were formed in the eyes of this young man, but they were of no use to him without the aid of experience, and the other senses. In what manner then do we represent magnitudes and distances to ourselves? and how do we judge of the figure and situation of objects? Certainly by the joint use of the senses of seeing and feeling together, and not by means of either of them separately employed. Neither the touch, nor the sight, can any more convey an idea of the figure or magnitude of a body to the mind, than the taste can convey an idea of colour.

After having acquired these ideas by experience, the mind has received impressions which remain with her for ever afterwards. Being now enlightened and instructed, she forms a judgment without entering into all the circumstances and deductions that were necessary for her first information; and, like a skilful artist, employs the fewest means to attain the end proposed. Having thoroughly acquainted ourselves with the objects around us, we find connections and relations that enable us to form a judgment of those that are more remote; and by creating to ourselves artificial organs, which supply the defects of the natural ones, we extend our faculties beyond the apparent limits prescribed to them by nature, and subject the sense of feeling to the sense of sight.

Astronomy has enlarged the sphere of our conceptions, and opened to us an universe without bounds, where the human imagination is lost. Surrounded by infinite space, and swallowed up in an immensity of being, man seems but as a drop of water in the ocean, mixed and confounded with the general mass. But from this situation, perplexing as it is, he endeavours to extricate himself, and by looking abroad into nature, employs the powers she has bestowed upon him in investigating her works. He proportions his own duration to that of the world; and representing to himself the insensible flux of time by similar analogies, he forms an idea of things which have no immediate existence, and places before his mind a picture of the past, present, and future state of the world.

These are the fruits of genius and curiosity. To an active and persevering mind apparent impossibilities become probable: where the will and desire are not wanting, we are always able to extend the circle of human activity beyond its ordinary limits. The progress of reason, and the powers of the imagination, are almost without bounds; and if we add to these, the invention of instruments, which are so many new organs of power and perception, man becomes a being worthy of admiration. He increases his strength by the assistance of the elements, augments and multiplies the powers of his senses, assures himself of their truth, and corrects their errors; and by this means creates to himself a new being, and adds to his faculties an extension and exactitude which nature seemed to have denied him.

It should appear, that Astronomy depends altogether upon the sight. This is the most extensive of all our senses: it transports us every where, and enables us to enjoy the entire spectacle of the universe.

"Takes in, at once, the landscape of the world,
At a small inlet, which a grain might close,
And half creates the wonderous world we see."

YOUNG.

But this sense, like all the rest, is subject to delusion; and requires frequent correction before it can give us a perfect idea of the situations, magnitudes and distances of bodies. Of those objects that are near to us we may form a conception, by subjecting them to a rigorous examination; but when they are inaccessible, and we have no means of transporting ourselves to them, it would seem that we have arrived at the utmost limits of our knowledge and power. When we look at the heavenly bodies, the sight represents them as very small, and the mind, at the same time, conceives them to be very large; but how do we know that they are in reality large? How is it that the mind contradicts the senses? And how, in this immense abyss of space, can we contrive to reconcile them to each other?

Some of the most simple contrivances have frequently given birth to the noblest inventions of art. We touch with a stick what we cannot reach with our hands, and this gives us an idea of distance and solidity, without approaching the object. A rod of wood, or metal, pointed towards the sun, or a star, in like manner, shows its direction; and by means of the visual ray, which passes along the rod, from the object to the eye, we obtain an idea of its situation; and thus assure ourselves of a truth, which the unassisted sight could never have acquainted us with.

But this is sufficient only for determining the direction of a single object; when there are two objects, or only one of a certain extension, it will inform us neither of their distance nor magnitude. We must now have two rods, or an instrument with two branches; and by directing the sight successively along each of these rods, their inclination or opening will present us with an exact measure of their distance. But how, it may be asked, can an angle determine the distance of objects? This is a new mode of measuring, apparently foreign to the purpose: lines are measured by other lines, of a certain length, surfaces by squares, and solids by cubes, or by their weight; but here the measure is an angle. How is the quantity of this angle to be determined? and when the quantities are different, how are they to be compared together?

These inventions are the produce of genius and penetration, their excellence being hid in the simplicity of the operations. If we represent to ourselves the time when Geometry was in its infancy, when men were not accustomed to consider the properties of figures, we may easily perceive how much they must have been embarrassed with these difficulties, and what talents and industry it required to conquer them. It must, undoubtedly, have been the work of time; many attempts, and many preliminary inventions, must have been previously thought of; which would be difficult because they were the first, and sublime because they were simple.

Simplicity is, at present, reckoned the supreme merit of all new inventions; and this is only to be obtained by superior minds; all great discoveries are generally preceded by tedious efforts, and a long complication of circumstances, which are often foreign to the purpose, but ending at last in a simple and happy conclusion which was never expected. If this be the case now arts and sciences have arrived to such a degree of perfection, and when minds are enlightened by a free communication with each other, how must it have been when the arts were in their infancy, and a single solitary genius was combating the prejudices of a gross multitude, whose ideas were as rude as their manners were barbarous.

In examining our new instrument, it may be observed, that as two stars become more distant from each other, we must open the rods accordingly, and make them recede farther from each other, by a movement of rotation, round that extremity which is common to them both. And by making them move entirely round the centre, we find that this revolution is always a certain fixed and invariable measure. Whatever be the distance of the two stars, whether great or small, the opening of the rods will be always an assignable part of the whole revolution; so that if the two rods be equal, and their extremities be made to move over a circle of wood or metal, the path described by them will immediately become known. And if the circumference of this circle be divided into equal parts, or degrees, we can tell what part of the circle the moveable rod has described; and thus every distance becomes measurable.

It was no doubt these ideas that first suggested the construction of the quadrant, which is an instrument of the greatest utility in astronomical observations; the most simple form of which is represented Pl. x. fig. 4. It consists of a quarter of a circle ABC, the circumference of which is divided into degrees and minutes. At the angular point is a pin A, on which is suspended a plummet or small heavy body D, at the end of a fine thread AD; by means of which, and the two sights *m*, *m*, on the side AB, the altitude of any body may be readily determined. Suppose, for example, the altitude of the star S were required; the oberver looking through the two sights *m*, *m*, brings them in a line with the star S; then marking the degree cut off by the plumb line AD, he has at once the altitude required; for the angles SAB and EAD being both right angles, if from each of these there be taken the common angle EAB, there will remain the angle of elevation EAS, equal to the angle BAD.

This simple, admirable instrument, and the measuring of celestial distances by means of angles formed by a circular movement, are contrivances of such extensive utility and importance, that they merit our highest encomiums. The authors of these inventions improved the sciences, and extended the circle of human intelligence. All that has been done since, has been only to advance a few steps farther in the same path. Our most ingenious and celebrated instruments are little more than this primitive instrument improved. The efforts and success of the moderns cannot be too much praised; but if the labour of ages has enabled us to correct our masters, we ought not to forget that they invented what we have brought so near to perfection.

Of all the instruments of this kind, of modern invention, that known by the name of Hadley's Quadrant is by far the most useful, in a portable form, of any that has yet been devised; being now always used at sea for finding the latitude and longitude, and for other nautical purposes. But as it depends upon optical principles, its construction cannot be conveniently explained in this place, without entering upon subjects with which you are at present unacquainted. It will therefore be sufficient to observe, that of the several instruments, similar to those above-mentioned, that represented in Pl. x. fig. 1. is justly esteemed the most accurate. This is generally called the mural arc, in consequence of its being fixed upon the face of a solid wall, to prevent any change in the position of the instrument. The observations are made by means of a telescope, which is fixed on and revolves about the angular point of the quadrant, and the degree of elevation of the object is marked on the limb, as in the preceding figure. This instrument, however, is commonly very large, and is made of brass or other metal, which renders it very expensive; so that it is seldom used except in observations, where the utmost accuracy is required.

The transit instrument, for observing the exact time of the sun or a star passing the meridian, is also represented in Pl. x. fig. 3. This consists of a telescope fixed very accurately in the plane of the meridian, and is supported by two strong stone pillars let into the ground, in order to prevent any deviation in the instrument from that direction. It is moveable on an axis in this plane, and the degree of elevation of the object, is shown by an index at one of its extremities; so that the transit, or passage of any body over the meridian may be accurately ascertained, at whatever distance it may pass from the zenith.

This being premised, it may now be observed, that Astronomy furnishes us with a variety of methods for determining the distances of the celestial bodies; but as many of them are involved in long calculations, which are intelligible only to mathematicians, I shall confine myself to those that admit of the most familiar explanation, and endeavour, by that means, to set the subject in so clear a light, that you can no longer doubt of the possibility of resolving this curious problem. We will first begin with the moon: this planet is nearer to us than any of the rest, and the method of finding her distance from the earth being once known, it will be easy to perceive that the distance of any other planet may be determined in nearly the same way.

The first thing to be done, in the method I am about to describe, is to find the moon's horizontal parallax, or the difference between the place of the moon when she appears in the horizon, to a spectator on the earth's surface, and her place as it would appear to a spectator placed at the earth's centre. This problem is no less curious than the one it is meant to elucidate: it is the same thing as to find the angle under which the semi-diameter of the earth would appear, at a certain time, to an observer placed at the centre of the moon. That this can be done, must appear very extraordinary to a person unacquainted with astronomical principles; but the determination, singular as it may seem, is far from being impracticable.

It will be sufficient to show you the bare possibility of the thing, without entering into the minutiæ of practice. For this purpose, let us suppose an observer to be placed upon any point A, of the equator BAC, (Pl. XI. fig. 1.) at the time the moon moves in the equinoctial DMP, then, as this latter circle is in the plane of the former, the moon will pass directly over his head, and descend perpendicularly to the horizon EN. In this situation of the spectator upon the earth's surface at A, the moon will appear to have described a quarter of a circle, or ninety degrees, in passing from the zenith M to the sensible horizon at N; but to a spectator placed at the centre of the earth O, she would appear to have described a quarter of a circle when she came to the rational horizon at P. But the moon revolves round the earth, from the meridian to the meridian again, in about twenty-four hours and forty-eight minutes; she will therefore revolve from M to P in six hours and twelve minutes; and if the time she takes in moving from M to N be found by observation, and taken from six hours twelve minutes, the time of moving from M to P, the remainder will be the time employed in describing the arc NP.

Having thus found the measure of the arc NP in time, we can convert it into degrees and minutes, as follows: As the time of describing the arc MN, which is found by observation, is to ninety degrees, so is the time of describing the arc NP, to the degrees and minutes in that arc. But this arc is the measure of the angle NOP, or of its equal ONA; for since the lines AN and OP are parallel to each other, it is a known property of geometry, that the angle NOP will be equal to the angle ONA. This angle ONA is called the moon's horizontal parallax, and as that is now found, we can easily determine the distance of the moon from the earth's centre. For it is a maxim in trigonometry, that when any three things in a plane triangle are known, except the three angles, the rest may be found by calculation.

Now, in the triangle AON we have the side OA, equal to half the diameter of the earth, which, from an actual mensuration of the circumference, has been found to be about three thousand nine hundred and sixty miles; the angle ONA, or the moon's horizontal parallax, has also been found by observation; and the angle OAN is a right angle, because OA is perpendicular to the sensible horizon EN. These three things, therefore, are known, and afford sufficient data for determining the rest. The side of the triangle ON is the distance of the moon from the centre of the earth O; and this distance, by a single trigonometrical operation, is found to be, at a mean rate, about sixty semidiameters of the earth, or, in round numbers, about two hundred and forty thousand miles.

But the true quantity of the moon's horizontal parallax cannot be accurately determined by this method, on account of the varying declination of the moon, and the inconstancy of the horizontal refractions, which are perpetually changing according to the state the atmosphere is in at the time. For the moon continues but for a short time in the equinoctial, and the refraction, at a mean rate, elevates her apparent place, near the horizon, half as much as her parallax depresses it. Astronomers have, therefore, thought of the following method, which is free from these objections, and if practised by able observers, with good instruments, is sufficient for determining the parallax and distance of the moon to a considerable degree of precision.

I shall mention the most simple case first, and this will render the general method more clear and satisfactory. Suppose two observers were placed under the same meridian at A and B (Pl. XI. fig. 2.) at such a distance from each other, that the one at A sees the moon M in his horizon, whilst the other at B sees her in his zenith; then will the distance of the moon OM, and the horizontal parallax OMA, be easily determined. For the arc AB, which measures the angle O, is equal to the difference of latitude of the two observers; the side OA is equal to three thousand nine hundred and sixty miles, the same as before; and the angle OAM is a right angle. In the triangle MAO, therefore, there is given one side and two angles, and consequently the side OM, or the distance of the moon from the centre of the earth, may be found by trigonometry, as in the former example. And if the angle O be taken from ninety degrees, it will give the angle M, which is the moon's horizontal parallax.

This is the simplest solution the problem admits of; but as it may not be easy to perceive how the two observers can be placed in the manner required, I shall now give you a more general method, by which the distance of the moon from the earth may be determined, when the observers are situated at any two distant places under the same meridian. Suppose, for example, that the two observers were at the points A and B (Pl. XI. fig. 3.) whose distance AB, or their difference of latitude, has been previously found, by the rules already laid down for that purpose; then if the zenith distances of the moon, ZM and zM, be each taken, with a good instrument, at the moment when she passes the meridian Zz, the distance of the moon MO from the centre of the earth may be determined as follows.

In the triangle ABO, OA and OB are each equal to the radius of the earth, or three thousand nine hundred and sixty miles; and the angle AOB is measured by the arc AB, which is the difference of latitude between the two observers at the time of observation. These three things therefore being known, the side AB, and the angles OAB and OBA, can be found by calculation. And if the angles MAZ and MBz, which are measured by the zenith distances MZ and zM, be each taken from a hundred and eighty degrees, the remainders will be the angles OAM and OBM; for it is a known property in geometry, that a line standing upon another line, makes with it two angles, which, taken together, are equal to two right angles.

From the angles OAM and OBM, thus determined, take the angles OAB and OBA, which have been found by caclulation, and there will remain the angles MAB and MBA: so that in the triangle ABM, we shall have these two angles, and the side AB; and consequently the side MB may also be found as before. This is sufficient for our purpose; we have now, in the triangle OMB, the two sides MB and BO, and the included angle OBM, and therefore the side OM, or the distance of the moon from the centre of the earth, may be determined. This might, however, have been done in a shorter way, by first finding the horizontal parallax; but as that method depends upon a theorem in trigonometry, the demonstration of which does not admit of a familiar explanation, I have chosen to follow rather a more prolix manner, for the sake of greater perspicuity.

LETTER XVIII.

THE SAME SUBJECT CONTINUED.

THE distance of the sun from the earth might be determined in nearly the same manner as that of the moon, if his horizontal parallax was not so small as to be scarcely perceptible; for it is well known, that the angle OSA, under which the semi-diameter of the earth would appear to a spectator in the sun, can never exceed nine seconds, or the four hundredth part of a degree. (Pl. XI. fig. 4.) And as a mistake of one second, in so small an angle, will occasion an error of about seven millions of miles in the distance, it is easy to perceive what an extraordinary degree of skill it must require, to surmount the difficulties attending this delicate subject.

But the mind grows stronger by frequent exertions, and genius and industry conquer difficulties apparently insurmountable. The vast bulk of the earth has been accurately measured; and the stars of heaven, that are visible to the naked eye, have been all numbered; and the immense distance of the sun is now subjected to a rigorous calculation. By means of the transit of Venus over the sun's disc, which happened in the years 1761 and 1769, this problem was resolved with a degree of precision, unlooked for by the Astronomers of ancient times. The person to whom we are indebted for this excellent method, is Dr. Edmund Halley; a man, whose skill and penetration in all mathematical and philosophical enquiries, entitles him to an eminent place in the classes of literature and science. A few extracts from the Dissertation which he presented to the Royal Society upon this subject, will show you the spirit of his method, and enable you to enter into the illustration of it with the greater facility.

"There are many things, he observes, that appear extremely paradoxical, and even quite incredible to the illiterate, which yet, by means of mathematical principles, are easily solved. Scarcely any thing will be thought more hard and difficult than that of determining the distance of the sun from the earth; but this, when we are made acquainted with some exact observations, taken at places fixed upon, and chosen beforehand, for that purpose, may, without much labour, be easily effected. And this is what I am now desirous to lay before this illustrious Society, that I may explain to young Astronomers, who may perhaps live to observe these things, the method by which the immense distance of the sun from the earth may be truly determined, to within, at least, a five hundredth part of what it really is.

"The distance of the sun from the earth is, by various Astronomers, supposed different, according to what was judged most probable, from the best conjectures they could form. Ptolemy, Copernicus and Tycho Brahe, imagined it to be about one thousand two hundred semi-diameters of the earth. Kepler thought it to be nearly three thousand five hundred; which distance is doubled by Riccioli, whilst Hevelius only increases it by one half. But Venus and Mercury having, by the assistance of the telescope, been seen to pass over the sun's disc, deprived of their borrowed brightness, it is at length found, that the apparent diameters of the planets are much less than they were formerly supposed; and that the semi-diameter of Venus, as seen from the sun, subtends no more than the fourth part of a minute, or fifteen seconds, whilst the semi-diameter of Mercury is seen, at a mean, under an angle of only ten seconds.

"It has been also found, that the semi-diameter of Saturn, seen from the sun, appears under the same angle as that of Mercury; and that the semi-diameter of Jupiter, the largest of all the planets, subtends an angle of no more than the third part of a minute. Whence some modern Astronomers, imagining that the semi-diameter of the earth, as seen from the sun, would subtend a mean angle, between the larger one of Jupiter, and the smaller one of Saturn and Mercury, have concluded, that the sun's parallax is about fifteen seconds, or equal to that of Venus, and that his distance from the earth is about fourteen thousand of the earth's semi-diameters.

"But this is an inference, the truth of which may be fairly questioned; for as the moon's diameter is a little more than one-fourth of the diameter of the earth, if the sun's parallax should be supposed fifteen seconds, it would follow that the body of the moon is larger than that of Mercury; that is, that a secondary planet would be greater than a primary; which should seem to be inconsistent with the uniformity of the mundane system.(*o*) And, on the contrary, the same regularity and uniformity seems scarcely to admit, that Venus, an inferior planet, that has no satellite, should be greater than the earth, which stands higher in the system, and has such a splendid attendant.

"Let us, therefore, observe a mean, and suppose that the semi-diameter of the earth, as seen from the sun, or, which is the same thing, the sun's horizontal parallax, is twelve seconds and a half; then, according to this supposition, the moon will be less than Mercury, and the earth larger than Venus; and the sun's distance from the earth will be found to be about sixteen thousand five hundred of the earth's semi-diameters. This distance I assent to, at present, as the true one, till it shall become certain what it is, by the experiment I am about to propose.

"Nor am I induced to alter my opinion by the authority of those, however weighty it may be, who are for placing the sun at an immense distance beyond the bounds here assigned, as observations made upon the vibrations of a pendulum, in order to determine those exceeding small angles, are not

(*o*) Though Dr. Halley was perfectly right in his conjecture of Mercury being greater than the moon; yet latter discoveries have shown, that it is not inconsistent with the mundane system, for a primary to be less than a secondary; as this is the case with the new planets Vesta, Juno, Pallas and Ceres.

sufficiently accurate to be depended upon; for by this method of investigating the parallax, it will sometimes come out to be nothing, or even negative; that is, the distance will either be infinite, or greater than infinite, which is absurd. And indeed, to confess the truth, it is hardly possible for a person to distinguish seconds with certainty, by any instruments, however skilfully they may be made; and therefore, it is not at all to be wondered at, that the excessive nicety of this matter should have eluded the many ingenious endeavours of such able operators.

"About forty years ago, when I was in the island of St. Helena, taking a catalogue of the stars near the south pole, I had an opportunity of observing the passage of Mercury over the sun's disc, which succeeded better than I could have expected; for, by means of a telescope twenty-four feet long, I determined the very moment when Mercury, entering upon the sun, seemed to touch his inward limb; and also, when in going off, it struck the limb of the sun's disc, forming the angle of interior contact; by which means I found the interval of time, during which Mercury appeared upon the sun, even without an error of a single second of time.

"For the lucid line, intercepted between the dark limb of the planet, and the bright limb of the sun, although exceedingly fine, may be easily seen by the eye; and the little dent made in the sun's limb, by Mercury's entering, or leaving the disc, appears, in the first case, to vanish, and, in the latter, to begin almost instantaneously. When I perceived this, it came immediately into my mind, that the sun's parallax might be accurately determined by such kind of observations as these, provided Mercury were nearer the earth, and had a greater parallax from the sun. But the difference of these parallaxes is always less than the solar parallax which we seek; and therefore Mercury, though he may frequently be seen in the sun, is not to be looked upon as fit for our purpose.

"There remains then, the transit of Venus over the sun's disc, whose parallax, being almost four times as great as the solar parallax, will cause very sensible differences between the times in which Venus will seem to be passing over the sun from different parts of the earth. And from these differences, if they be properly observed, the sun's parallax may be determined, even to a small part of a second. Nor are any other instruments required for this purpose, than common telescopes, and clocks, which are good of their kind; and in the observers, nothing more is requisite than fidelity, diligence, and a moderate skill in Astronomy.

"For there is no need that the latitude of the place should be scrupulously observed, nor that the hours themselves should be accurately determined with respect to the meridian: it is sufficient that the clocks be regulated according to the motion of the heavens, provided the times be accurately reckoned from the total ingress of Venus into the sun's disc, to the beginning of her egress from it; that is, when the dark globe of Venus first begins to touch the bright limb of the sun within; which moments I know, by my own experience, may be observed to within a second of time.

"But on account of the very strict laws by which the motions of the planets are regulated, Venus is seldom to be seen within the sun's disc; and during the course of one hundred and twenty years it could never be once observed; namely, from the year 1639 (when this most pleasing sight happened to that excellent youth Horrox, our countryman, and to him only since the creation) to the year 1761; in which year, according to the theories that have been hitherto found agreeable to the celestial motions, Venus will again pass over the sun, on the 26th of May, in the morning; so that at London, about six o'clock in the morning, we may expect to see her near the middle of the sun's disc, and not above four minutes of a degree south of his centre.

"The whole duration of this transit will be almost eight hours; namely, from two o'clock in the morning to a little before ten; and therefore the ingress will not be visible in England; but as the sun will, at that time, be in the sixteenth degree of Gemini, having near twenty-three degrees of north declination, it will be seen without setting in almost every part of the north frigid zone: and, therefore, the inhabitants of the coast of Norway, beyond the city of Drontheim, as far as the North Cape, will be able to observe Venus entering the sun's disc; and perhaps the ingress of Venus upon the sun, when rising, will be seen by the

Scotch in the northern parts of the kingdom, and by the inhabitants of the Shetland Isles, formerly called Thule.

"But at the time when Venus will be nearest the sun's centre, the sun will be vertical to the northern shores of the Bay of Bengal, or rather over the kingdom of Pegu, near the mouth of the Ganges; and, therefore, as the sun, when Venus enters his disc, will, in the adjacent countries, be almost four hours towards the east, and as many towards the west when she leaves it, the apparent motion of Venus over the solar disc will be accelerated by almost double the horizontal parallax of Venus from the sun; because Venus, at that time, is carried with a retrograde motion from east to west, whilst a spectator, placed upon the earth's surface, is turned the contrary way, from west to east.

"Supposing, therefore, the sun's parallax to be twelve seconds and a half, as I have before conjectured, the parallax of Venus will be forty-three seconds; from which, if the former be subtracted, there will remain thirty seconds and a half, for the horizontal parallax of Venus from the sun: and, therefore, at those places which lie near the tropic, the motion of Venus will be increased by that parallax forty-five seconds at least, whilst she passes over the sun's disc; and still more so at all places which are situated near the neighbourhood of the equator.

"Now Venus, at that time, will move on the sun's disc, very nearly at the rate of four minutes of a degree in a hour, and therefore eleven minutes of time, at least, are to be allowed for the forty-five seconds of a degree above-mentioned; which, therefore, is the space of time the duration of the eclipse, caused by Venus, will, on account of the parallax, be shortened. And from this diminution of the time only, we might safely enough draw a conclusion concerning the parallax which we are in search of, provided the apparent diameter of the sun, and the latitude of Venus, were accurately known; but in a matter of such subtlety we cannot expect an exact computation.

"We must therefore endeavour to obtain, if possible, another observation, to be taken in those places where Venus will be in the middle of the sun's disc at midnight; that is, in places under the opposite meridian to the former; or about six hours, or ninety degrees west of London; and where Venus enters upon the sun's disc a little before sun-set, and goes off a little after its rising. And this will happen under the above-mentioned meridian, and where the elevation of the north pole is about fifty-six degrees; that is, in a part of Hudson's Bay, near a place called Port Nelson. For in this, and the adjacent countries, the parallax of Venus will increase the duration of the transit, by at least six minutes of time; because, whilst the sun, from his setting to his rising, seems to pass under the pole, those places on the earth's surface will be carried from east to west, or with a motion conspiring with that of Venus; and therefore Venus will seem to move more slowly on the sun, and to be longer in passing over his disc.

"If therefore it happens that this transit should be properly observed, by skilful persons, at both these places, it is clear, that the duration of it will be seventeen minutes longer as seen from Port Nelson, than as seen from the East Indies. Nor is it of much consequence whether the observation be made at Fort George, commonly called Madras, or at Bencoolen, on the western shore of the island of Sumatra, near the equator. But if the French should be disposed to take any pains in this affair, an observer may station himself conveniently enough at Pondicherry, on the western shore of the Bay of Bengal, where the altitude of the pole is about twelve degrees.

"As to the Dutch, their celebrated mart at Batavia will afford them a place of observation fit enough for this purpose, provided they also have a disposition to assist in advancing the knowledge of the heavens in this particular. And, indeed, I could wish that many observations of the same phænomenon might be taken, by different persons, at several places; both that we might arrive at a greater degree of certainty by their agreement, and also lest any single observer should be deprived, by the intervention of the clouds, of a sight, which I know not whether any man living will ever see again; and on which depends the certain and adequate solution of a problem the most noble in the sciences.

"I recommend it, therefore, again and again, to those curious Astronomers, who may have an opportunity of observing these things when I am dead, that they would remember these admonitions, and diligently apply themselves with all their might to the making of the necessary observations; in which I earnestly wish them all imaginable success: in the first place, that they may not, by the unseasonable obscurity of a clouded sky, be deprived of this most desirable sight; and then, that having ascertained with more exactness the magnitude of the planetary orbits, it may redound to their immortal fame and glory.

"And thus have I shown," the Doctor observes, "that, by this method, the sun's distance may be determined to within its five hundredth part, which will doubtless appear very extraordinary to some. But if an accurate observation be made at each of the places above-mentioned, I have already demonstrated that the durations of the eclipse made by Venus, will differ from each other by seventeen minutes of time; that is, upon a supposition that the sun's parallax is twelve seconds and a half. But if the difference should be found, by observation, to be greater or less, the sun's parallax will be greater or less in nearly the same proportion. And since seventeen minutes of time answer to twelve seconds and an half of solar parallax, for every second of parallax there will arise a difference of more than eighty seconds of time; so that if we have this difference true to two seconds, it will be certain what the sun's parallax is, to within a fortieth part of a second; and therefore his distance will be determined to within its five hundredth part at least, if the parallax be not found less than we have supposed; for forty times twelve and a half is five hundred."

The Doctor having pursued his subject thus far, in this popular and easy way, proceeds to illustrate it by a figure; but as he has introduced several things into his calculation which could not be understood by a person unacquainted with mathematical principles, I shall endeavour, by means of a simple unembarrassed scheme, to give you such an idea of the matter, as will at once convince you of the practicability and certainty of this method. The two last transits were in the years 1761 and 1769, and as there will not be another before the year 1874, when most of the human race, now living, will in all probability be dead, it will be unnecessary to trouble you with a long account of the methods made use of for observing these eclipses with accuracy and precision, or to enter into any other particulars, than what are sufficient for our present purpose.

In the preceding letter, I explained to you what was to be understood by the parallax of any of the celestial bodies (Pl. XI. fig. 1 and 2.); but as I shall, in the present instance, have to consider the same a little differently, it will be proper again to enter upon this subject. Let then AE (Pl. XII. fig. 1.) represent the earth, C its centre, and A a point on its surface; also let V and S represent any two celestial objects, as, for example, Venus and the Sun.

Then from what has been already explained, the angle AVC will be the parallax of Venus, and ASC the parallax of the sun; and if AS, AV and CVS be produced to T, *v*, and *s*; then will also the angle *s*V*v* be the parallax of Venus, and *s*ST the parallax of the Sun; the former being measured by the arc *sv*, and the latter by the arc *s*T. And since the angle subtended by AC, whether taken from V or S, is very small, it may be considered as being reciprocally proportional to the distance of V and S from the centre C; that is, if S be at double the distance of V, then the angle ASC, or *s*ST, will be half the angle AVC, or *s*V*v*; and if the distance of S from C, be treble that of V, then will the former angle be only one third of the latter, and so on.(*p*)

Hence, since we know the proportional distance of Venus and the Sun; it follows that we also know the proportion of their parallaxes, or which is the same, the ratio of the two arcs *s*T and *s*V; and consequently if we could find either of these, or their sum, or difference, we might, by a simple process, find the particular parallax of each; for the ratio and difference of any

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(*p*) This may not appear quite evident; but it may be shown thus by plain trigonometry:

as CV : 1 :: CA : tan. ∠AVC

CS : 1 :: CA : tan. ∠ASC

therefore, CV : CS :: tan. ∠ASC : tan. ∠AVC

that is, the tangents of the angles are reciprocally as the radii. But in very small arcs, the tangents may be made to represent the arcs; and as the arcs are the measures of the angles, the angles also are reciprocally as the radii.

two quantities being given, the quantities themselves are readily ascertained.

This being understood, you will find no difficulty in comprehending the following illustration. Let s's (Pl. XII. fig. 2.) represent the Sun, and vv', Venus, in those two points of her orbit where the transit begins and ends, as seen from the earth's centre; and let EE' be the corresponding positions of the earth in its orbit at those times.

Then if an observer could be placed at C, he would perceive Venus just entered upon the eastern limb of the sun, where she would appear like a small black spot as at s; and the true place of both as referred to the heavens, would be at *s*. But to an observer on the earth's surface at A, the apparent place of Venus would be at *v*; and the apparent place of the sun's eastern limb at T; that is, she would appear to be to the eastward of the sun, and at a distance equal to the arc T*v*, or the difference of the parallax of these two bodies; and therefore, the immersion of Venus upon the sun's disc, would not take place so soon to the observer at A, as to the one at C, by the time Venus employs in describing the apparent arc *v*T.

Now, as the transit always happens at the time of an inferior conjunction, the motion of Venus and the Earth at those points of their orbits will be retrograde, or from east to west, while the rotatory motion of the earth on its axis is performed from west to east; hence it is obvious, that while Venus moves in her orbit from v to v', and the earth from E to E', the point A, on its surface, which was at first westward of its centre, will be now to the eastward of it, as at A′; and therefore, for the same reason as before, while the observer at C, perceives Venus just quitting the sun's disc, he who is placed at A′, will see her to the westward of the sun as at *v*′; the apparent place of the sun's western limb being at T′; and consequently the apparent distance of Venus from the sun at this time, will be the arc *v*′T′; which is the measure of the difference of the parallaxes of these two bodies as before. The whole duration therefore of the transit as seen at the point A, on the surface of the earth, will be less than the absolute duration, by the time that Venus is describing the two apparent arcs *v*T, T′*v*′, or double the difference of the parallaxes.

And as the absolute duration of the transit may be ascertained from calculation, and the apparent duration of it from observation, the difference of the times will thus become known; and hence, the measure of the apparent arc described by Venus in that time; which, as we have before seen, will be double the difference of the parallax of these two bodies. Having thus, then, found the difference of their parallaxes, and knowing before the ratio of them, we can readily determine the particular parallax of each. But the parallax of the sun being the angle which the semi-diameter of the earth subtends at the distance of the sun, and this semi-diameter being itself known, the distance of the sun from the earth may be easily ascertained from the first principles of trigonometry.

The transits which happened in the years 1761 and 1769, were observed with the greatest accuracy and diligence by some of the most eminent Astronomers in Europe, who were sent out to the most convenient parts of the earth for that purpose; and from their determinations it appears, that the horizontal parallax of the sun is, at a mean, about eight and a half seconds, and his distance from the earth, in round numbers, about ninety-three millions of miles. A distance so prodigious, that a cannon-ball, which is known to move at the rate of about eight miles in a minute, would be something more than twenty years in going from the earth to the sun; and if a spectator could be placed in the sun, and was to look at the semi-diameter of the earth, this line, which is about four thousand miles long, would only appear to him under an angle of about eight and a half seconds. Consider this, and you will find it a subject worthy of your admiration and wonder.

The distance of the sun from the earth being thus found, the distances of all the rest of the planets may be easily determined, by the stated laws of nature. For it was discovered by Kepler, from observation, that the squares of the periodic times, in which the planets perform their annual revolutions, are in proportion to each other as the cubes of their mean distances from the sun; so that the distance of any one of them being known, the distance of any other may be easily determined. Suppose, for example, that I wanted to know the distance of Saturn from the sun; this may be performed by the rule of proportion, as follows: As the square of the time in which the earth performs her revolution round the sun, is to the square of the time in which Saturn performs his revolution round the sun, so is the cube of the earth's mean distance from the sun, to the cube of the mean distance of Saturn; and if the cube root of this last number be taken, it will give the distance of Saturn from the sun, as was required.

And in a manner equally easy, may the real diameters and bulks of the planets be determined, from their apparent diameters and distances being known. The sun and moon, for instance, appear nearly of the same magnitude; and therefore, if the sun's distance from the earth be reckoned at ninety-three millions of miles, his solid bulk, in order that he may appear as large as the moon, whose distance does not exceed two hundred and forty thousand miles, must be sixty-four millions of times as great as that of the moon's. Again, the earth's diameter, as seen from the sun, at the time of his mean distance, subtends an angle of double the sun's horizontal parallax, which is now supposed to be eight and a half seconds; and the sun's diameter, as seen from the earth, at that time, is found to be about thirty-two minutes; and, therefore, the sun's diameter is to the earth's as 1920 to 18. And, since the magnitudes of spherical bodies are to each other as the cubes of their diameters, the bulk of the sun will be to that of the earth as 7077888000 to 5832, or something more than a million of times larger. And, in the same manner, may the diameters and magnitudes of the rest of the planets be readily determined.

Another problem, equally curious with the former, and apparently involved in still greater difficulties, is to determine the densities or comparative masses of the sun and planets, with respect to that of the earth. To ascertain the weights of the celestial bodies which are placed at such an immense distance from us, seems indeed, at first sight, too great an undertaking for the limited powers of the human faculties. But, as I have observed on a former occasion, difficulties presented to an active mind, instead of repressing its ardour and retarding its progress, serve only to stimulate it to greater exertions and nobler pursuits. You have seen already by what means the magnitudes and distances of the planets have been ascertained, and I will now endeavour to render the present subject equally clear and perspicuous; previous to which, however, it will be proper to explain to you what is meant by the density of a body.

By this term, then, you are to understand the greater or less quantity of matter that is contained in things of the same magnitude; or, since their weights also depend upon the matter they contain, the density of two or more bodies of the same size, may be regarded as proportional to their weights. Thus, if in two bodies of equal bulk, the one contains double the mass, or quantity of matter, or double the weight of the other, its density is also double; if it weigh three times as much, its density is treble, and so on. Whence again it follows, that the densities of bodies of different magnitudes, may be expressed or measured by their masses divided by their bulks; and therefore, by knowing the masses and magnitudes of any number of bodies, we can immediately ascertain their proportional densities. And since we have seen how their magnitudes may be determined, it only remains for me to explain, by what means we are enabled to arrive at a knowledge of their masses, for this is all that is necessary in our present enquiry, since the rest may be determined by common division.

In order to this, we must again have recourse to the force of gravitation, which decreases, as the square of the distances increase, while the attracting body remains the same; but when bodies of different masses are compared, the attractive power will be reciprocally as the squares of the distances, and directly as the attracting mass; that is, a double mass will have a double attractive power at the same distance, a treble mass a treble power, and so on. If, therefore, we can by any means ascertain the relative attractive powers of any two of the planets, this will give us their relative masses, from which, and their magnitudes which are supposed known, their densities with respect to each other will also be determined.

Now the ratio of this attractive power between the earth and sun is easily ascertained; for a body at the earth's surface, or at the distance of one semi-diameter from its centre, is known from experiment to fall through $16\frac{1}{12}$ feet in the first second of its descent; and since the spaces described at different distances from the centre, are reciprocally as the squares of those distances, it may be readily computed what space a body would fall through in one second, when placed at the distance of the sun. And since the diameter of the earth's orbit is known, we can likewise easily ascertain how much this body is deflected from its tangent in one second, by the attractive power of the sun; or, which is the same, what space a body would descend through in one second towards the sun, when placed at the mean distance of the sun from it. And we have before seen what space would be described by a body descending towards the earth in the same time, and placed at the same distance; therefore, since the spaces are as the attractive powers, and these latter are as the masses of the attracting bodies, we have at once, by comparing the spaces, the relative proportion of the masses of the earth and sun; and then again dividing their relative masses by their absolute magnitudes, we obtain their proportional densities.

From this computation it will appear that the density of the earth is to the density of the sun, as 4 is to 1; and as the density of the earth is known from other experiments to be to the density of water, as $5\frac{1}{2}$ to 1; it follows, that the density of the sun is to that of common water as $1\frac{3}{8}$ to 1. We cannot, however, proceed in the same manner with the other planets, because we have no means of ascertaining their respective attractive powers at their surfaces; on which account we must have recourse to their satellites, by comparing the deflection of each of them from its tangent with their respective distances from their primaries. For example, in order to find the relative densities of the Earth and Jupiter, we must first estimate how much the moon is deflected from its tangent in one second by the attractive power of the earth, and how much it would be deflected in the same time if it were placed at the same distance from the centre of the earth, as any one of Jupiter's satellites is from the centre of that planet; which distances are all known from their periodic times being given, by the second law of Kepler.

By this means, we shall have the absolute spaces described by two bodies in the same time towards the Earth and Jupiter; and these spaces, as we have before seen, being as the attractive power of the two bodies, and the attractive powers as their masses, it follows, that by comparing as above, the spaces described, we shall obtain the ratio of the masses; the division of which by their absolute magnitudes, will give us their proportional densities; from which computation it appears, that the density of Jupiter is to that of the earth as $\frac{23}{100}$ to 1, being a little less than the density of the sun, and a little more than that of sea water.

It is likewise obvious, that the same method may be employed for determining the density of Saturn and Uranus; but those planets which have no satellites, cannot be submitted to the same calculation; nor can I render the method that is made use of in these cases intelligible to you, as it requires a knowledge of some of the higher branches of mathematics; you must therefore, for the present, rest contented with the information you have acquired on this subject, which is undoubtedly as important and interesting, as any that falls under the contemplation of the human mind.

LETTER XIX.

OF THE MOTION, REFRACTION, AND ABERRATION OF LIGHT.

HAVING measured the globe of the earth, and determined the distances of the sun, moon, and planets, let us now consider the phænomena of light; a subject of no less importance than the former, and equally deserving your attention. It is in this branch of philosophy that the genius of Newton shines with uncommon lustre; and were I allowed to follow him through all his optical experiments and enquiries, I could present you with some of the most astonishing instances of human sagacity that the history of man affords. But as the nature of my plan admits not of such extensive digressions, I shall confine myself to those discoveries which are connected with astronomical observations, and leave the rest for your future consideration.

Various opinions have been entertained concerning the nature of light. The Greeks considered it as an accident, or property, resulting from the first principles of things; and Descartes defines it to be a globulous matter, diffused through the universe; which being impelled by the sun, strikes upon our eyes, in the same manner as a staff that is pushed at one end presses in the same instant at the other. Moses makes light to have been the first of created things; and Milton, in one of the noblest invocations that poetry can boast, thus expresses the same sentiment.

> "Hail, holy light, offspring of Heav'n first-born,
> Or of th' Eternal co-eternal beam,
> May I express thee unblam'd? since God is light,
> And never but in unapproached light
> Dwelt from eternity, dwelt then in thee,
> Bright effluence of bright essence increate.
> Or hear'st thou rather, pure ethereal stream,
> Whose fountain who shall tell? before the sun,
> Before the heav'ns thou wert, and, at the voice
> Of God, as with a mantle didst invest
> The rising world of waters dark and deep,
> Won from the void and formless infinite."

The sacred author places the formation of light four days before that of the sun; and in this he appears to have been followed by all the philosophers of antiquity. It was, in those times, the general opinion, that the sun was not the source of light, but that he served to impel and spread it through space.

> "Of all celestial bodies first the sun
> A mighty sphere he fram'd, unlightsome first,
> Though of ethereal mould: then form'd the moon
> Globose, and every magnitude of stars,
> And sow'd with stars the heav'n thick as a field.
> First in his east the glorious lamp was seen,
> Regent of day, and all th' horizon round
> Invested with bright rays, jocund to run
> His longitude through heav'n's high road; the gray
> Dawn, and the Pleiades before him danc'd,
> Shedding sweet influence."
>
> MILTON.

This is the language of poetry, sublime and energetic, but not strictly conformable to truth; for it is now generally allowed that light is a material substance, which flows directly from the sun; and we are also able to ascertain the velocity with which it moves. M. Roemer, a Danish philosopher, was the first who showed, that it employs about eight minutes in its passage from the sun to the earth; and as this singular doctrine will naturally excite your attention, I shall give you his explication of it, in as easy and familiar a way as possible. The idea was first suggested to him by observing the eclipses of Jupiter's moons, and the conclusion was deduced as follows.

Let A and B (Pl. IV. fig. 13.) be the earth in two different points of its orbit, whose distance from each other is equal to the earth's distance from the sun's; it is then plain, that if the motion of light were instantaneous, the satellite I would appear, to a spectator at A, to enter into Jupiter's shadow SS, at the same moment of time, as to another spectator at B. But from a great number of observations it was found, that when the earth was at B, the emersion of the satellite into the shadow happened sooner, by about eight minutes, than when the earth was at A, and therefore the motion of light must be progressive, or such as would carry it through a space equal to the radius of the earth's annual orbit in about eight minutes of time. So that if the sun were annihilated, we should see him for eight minutes afterwards; and if he were again created, it would be eight minutes before we could observe him.

The same thing may also be shown thus: The instant when any of these eclipses will happen can be easily determined by calculation, because the times, in which they perform their revolutions, are known; and as it is constantly found, by observation, that any one of the satellites is eclipsed about sixteen minutes sooner when the earth is nearest to Jupiter, than when it is farthest from him, it is evident, that this must be occasioned by the time that light takes in moving through the diameter of the earth's orbit; for that these accelerations are not owing to any inequalities in the motions of the satellites themselves, is plain, because they are always affected alike, in whatever parts of their orbits they are eclipsed.

This explication furnishes us with the solution of one of the most curious problems that ever was attempted; which is that of determining the velocity of light. The minutest particles which are thrown off from the body of the sun, move through a space of ninety-three millions of miles in eight minutes; which is about a million of times swifter than the motion of a cannon-ball, when it is first projected from the mouth of a piece of ordnance; a rapidity too great for the imagination to follow, or the mind to comprehend. And yet, prodigious as such a motion appears, there may be stars, whose light has not reached us since the creation of the world. This is the universe of the poet;

————"Without bound,
Without dimension, where length, breadth, and height,
And time and place are lost."

The quantity of light and heat which the planets receive from the sun, decreases in proportion as the squares of their distances increase; and when a ray of light passes out of one medium into another, it is refracted or turned out of its course, according as it falls more or less obliquely on the refracting surface which divides the two mediums. The first of these propositions will appear evident, from the consideration of a cone of rays, flowing from any luminous point, the circular sections of which will be always proportional to the squares of their distances from the vertex; and therefore, reciprocally, the number of rays falling on the same surface will decrease, as the squares of the distances decrease; which latter circumstance may be exemplified as follows. Put a shilling into an empty bason, and retire to such a distance, that the edge of the bason shall just hide it from your sight; then, keeping yourself steady, let another person fill the vessel gently with water; and as the water rises towards the top, the object will become more and more visible, till at length the whole of it will be distinctly seen, appearing as if it had been raised above the bottom of the bason.

This proves that the rays of light are refracted, or bent downwards, in their passage out of the water into the air; and as they now come to the eye in a more oblique direction, the object must necessarily appear to be elevated, and in a different situation from that in which it was really placed. The same thing may also be shown thus: Place the bason in such a manner that the sun may shine obliquely on it, and observe where the shadow of the rim falls upon the bottom; then fill it with water, and the shadow will not extend so far as it did when the vessel was empty; which shows that the rays have changed their direction, by passing out of one medium into another of a different density.

The less obliquely the rays fall, the less they will be refracted; and if they fall perpendicularly, they will not be refracted at all. For, in the last experiment, the higher the sun rises, the less will be the difference between the places where the edge of the shadow falls, in the empty and full bason: and if a stick be laid across the bason, and the sun's rays be reflected perpendicularly into it from a looking-glass, the shadow of the stick will fall upon the same part of the bottom, whether the bason be full or empty. The same effects will also take place when the experiment is performed with any other fluid: but the denser the medium, the more will light be refracted in passing through it.

From these observations it will readily appear, that objects can seldom be seen in their true places. We are deceived by every thing around us: the sight is no less subject to error than the rest of our senses: they all contribute to our pleasure, and promote our happiness by various means. In consequence of this property of refraction, we enjoy the light of the sun whilst he is yet below the horizon; this being the cause that produces the crepusculum, or the morning and evening twilight. The sun's rays, in falling upon the higher part of the atmosphere, are reflected back to our eyes, and form a faint light, which gradually augments till it becomes day. It is in those brilliant colours that paint the clouds, before the rising of the sun, that the poets have placed Aurora, or the goddess of the morn: she opens the gates of day with her rosy fingers; and the daughter of the air and the sun has her throne in the atmosphere.

Had no such atmosphere existed, the rays of light would have come to us in straight lines, and the appearance and disappearance of the sun would have been instantaneous; we should have had a sudden transition from the brightest sunshine to the most profound darkness, and from thick darkness to a blaze of light. Refraction, therefore, is extremely useful, not only as it prepares us gradually for the light of the sun, but also as it occasions twilight, and by that means prolongs the duration of the day. Nature has established these gradations, to heighten our pleasures by variety; the scene is perpetually changing, but the order of things is immutable and eternal.

"Look nature through, 'tis revolution all,
All change, no death: day follows night, and night
The dying day; stars rise, and set, and rise;
Earth takes th' example: see the Summer gay,
With her green chaplet, and ambrosial flow'rs,
Droops into pallid Autumn; Winter gray,
Horrid with frost, and turbulent with storm,
Blows Autumn and his golden fruits away,
Then melts into the Spring; soft Spring, with breath
Favonian, from warm chambers of the south,

Recalls the first: all, to reflourish, fades;
As in a wheel, all sinks, to re-ascend."

YOUNG.

The refractive power of the atmosphere appears to have been known to astronomers before the time of Ptolemy; but the first who determined its effect, and employed it in correcting astronomical observations, was Tycho Brahe. He found, that the horizontal refraction was about thirty-three minutes, which is nearly the same as it is estimated at present; and by means of an instrument, contrived for that purpose, attempted to ascertain the quantity of it at different altitudes. But though Tycho had discovered the effect, he was not so happy in explaining the cause of this phænomenon. He attributed it to the gross vapours that float in the atmosphere, and imagined the refraction of the sun to be different from that of the stars; the former he supposed to extend no further than to forty-five degrees of altitude, and the latter only to twenty. But Dominique Cassini showed the fallacy of this doctrine, by calculating the refractions for every degree of altitude, and proving, that they diminish from the horizon to the zenith.

This determination is agreeable to modern discoveries; but in order that the subject may appear in its true light, I shall elucidate it by a figure. For this purpose, let T (Pl. IX. fig. 5.) represent the earth, surrounded with its atmosphere AED; S the sun, or a star; and O the place of the spectator upon the earth's surface. Then it is evident, that a ray of light SA, falling upon the gross body of the air at A, will be refracted, or bent towards the line QP, which is perpendicular to the surface of the atmosphere at that point; and because it is known from experience, that the air is denser in the lower regions of the atmosphere, than in the higher, the same ray will be refracted, not only at A, but at many other points in the medium, before it reaches the spectator at O. But as it is only the last part of the ray CO that affects the sight, the eye will naturally refer the object to *s*, in the straight line OC*s*, and will therefore see it in a situation much higher above the horizon than it really is.

And the higher the sun rises, the less will his rays be refracted, because they fall less obliquely on the surface of the atmosphere. Thus, when the sun is in the zenith, his rays will fall perpendicularly upon the atmosphere at B, and continue their course in the right line SBO. But when the sun is below the horizon RH, his rays, falling upon the atmosphere at F, will be bent downwards towards the observer at O; and he will now see the sun in the direction of the refracted ray O*as*, which lies above the horizon, and being extended to the heavens, shows the sun in the point *s*. When the ray SF is a tangent to the surface of the atmosphere at F, it is then the beginning, or end of twilight, according as the sun is rising or setting: and as this is known to take place when the sun is about eighteen degrees below the horizon, it has thence been found, by a trigonometrical process, that the height of the atmosphere is about forty-five miles, which agrees with the result of barometrical experiments made in balloons, and on the tops of high mountains.

It must also be observed, that the state of the atmosphere is exceedingly variable, and that the quantity of refraction is not always the same at the same altitude; for as heat diminishes the density of the air, and cold increases it, the refraction must alter accordingly; and, therefore, no rule can be given by which we can precisely ascertain, either the height of that part of the atmosphere which refracts the sun's rays, or the true place of any of the celestial bodies which are observed through this medium. But it is not from refraction only that we are unable to find the true places of those objects; they are also subject to other irregularities, which arise from their parallax, and the motion of light. The former of these I have already explained, and I shall now give you some account of the latter. It is a discovery of the celebrated Dr. James Bradley; and as the subject is exceedingly curious and important, I shall present you with the history of it in nearly his own words.

Dr. Bradley, in conjunction with the Honourable Samuel Molineux, Esq., in the year 1725, formed a project of verifying, by a series of new observations, those which Dr. Hook had communicated to the public about fifty years before. And as Hook's attempt was what principally gave rise to this, so his method in making the observations was in some measure that which they followed; for they made choice of the same star, and their instrument was constructed upon almost the same principles. But if it had not greatly exceeded the Doctor's in exactness, they might yet have remained in great uncertainty as to the parallax of the fixed stars. Their success, indeed, was chiefly owing to the ingenious Mr. George Graham, F.R.S. to whom the lovers of astronomy are also greatly indebted for several other exact and well-contrived instruments.

Mr. Molineux's apparatus was completed, and fitted for observing, about the end of November 1725; and on the third day of December following, the bright star in the head of Draco, marked γ by Bayer, was first observed, as it passed near the zenith, and its situation carefully taken with the instrument. The like observations were also made on the fifth, eleventh, and twelfth days of the same month; and there appearing no material difference in the place of the star, a farther repetition of them, at that season, seemed needless; it being a part of the year in which no sensible alteration of parallax, in this star, could soon be expected.

It was chiefly curiosity, therefore, which tempted Dr. Bradley, who was then at Kew, where the instrument was fixed, to prepare for observing the same star on December the 17th; when, having adjusted the instrument as usual, he perceived that it now passed a little more southerly, than when it was before observed. Not suspecting any other cause of this appearance, they at first concluded that it was owing to the uncertainty of their observations, and that either this, or the foregoing, were not so exact as they had before supposed; for which reason they proposed to repeat the observation, in order to determine whence this difference proceeded; and upon doing it, on the 20th of December following, it was found that the star passed still more southerly than in the former observations.

This sensible alteration the more surprised them, as it was in a contrary way from what it would have been, had it proceeded from an annual parallax of the star. But being now well satisfied that it could not be entirely owing to a want of exactness in the observations, and having no conception of any thing else that could cause such an apparent motion as this in the star, they began to think that some alteration in the materials, &c. of the instrument itself might have occasioned it. Under these apprehensions they remained some time; but being at length fully convinced, by repeated trials, of the great exactness of the instrument, and finding, by the gradual increase of the star's distance from the pole, that there must be some regular cause which produced it, they took care to examine nicely, at the time of each observation, how much it was: and about the beginning of March 1726, the star was found to be twenty seconds farther southerly than at the time of the first observation. It now, indeed, seemed to have arrived at its utmost limit southward; because, in several trials made about this time, no sensible difference was observed in its situation: but in the middle of April following, it appeared to be returning back again towards the north; and about the beginning of June it passed at the same distance from the zenith, as it had done in December, when it was first observed.

From the quick alteration of the star's declination about this time, which was near a second in three days, they concluded, that it would now proceed northward, as it before had gone southward; and their conjecture was not ill founded; for the star continued to move northward till September following, when it again became stationary, being then near twenty seconds more northerly than it was in March. From September it returned towards the south, till it arrived, in December, at the same situation which it was in a twelvemonth before, allowing for the difference of declination on account of the precession of the equinox. This was a sufficient proof, that the instrument had not been the cause of the apparent motion of the star, and to find one adequate to such an effect, seemed a difficulty.

A nutation of the earth's axis was one of the first things that offered itself on this occasion, but this was soon found to be insufficient; for though the change of declination in γ Draconis, might have been accounted for by it, yet it would not, at the same time, agree with the phænomena of the other stars, particularly with a small one, almost opposite to it, in right ascension, and at about the same distance from the north pole of the equator; for though this star seemed to move the same way as a nutation of the earth's axis would have made it, yet as it appeared, upon a comparison of the observations made upon the same days, at different seasons of the year, that it changed its declination about half as much as γ Draconis in the same time, this plainly proved, that the apparent motion of the star was not occasioned by a real nutation; since, if that had been the cause, the alteration in both stars would have been nearly equal.

The great regularity of the observations left no room to doubt, that this unexpected motion was owing to some regular cause, and did not depend on the uncertainty or variety of the seasons of the year; and upon comparing the observations with each other, it was discovered, that in both the stars before-mentioned, the apparent difference of declination from the maxima, was always nearly proportional to the versed sine of the sun's distance from the equinoctial points. This induced them to think, that the cause, whatever it was, had some relation to the sun's situation with respect to those points. But as they were not able to frame any hypothesis at that time, sufficient to solve all the phænomena, and were yet very desirous of searching a little farther into this matter, Dr. Bradley began to think of erecting an instrument for himself at Wansted; that, having it always at hand, he might, with the more ease and certainty, enquire into the laws of this new motion.

The consideration likewise of being able, by another instrument, to confirm the truth of the observations hitherto made with Mr. Molineux's, was no small inducement to him; but his principal motive was the opportunity it would afford him, of trying in what manner other stars were affected by the same cause, whatever it was. For as Mr. Molineux's instrument was originally designed for observing γ Draconis, it was so contrived, as to be capable of little more alteration in its direction than about seven or eight minutes of a degree; and there being few stars within half that distance from the zenith of Kew, bright enough to be well observed, he could not, with his present instrument, thoroughly examine how this cause affected stars differently situated, with respect to the equinoctial and solstitial points of the ecliptic.

These considerations determined him; and by the contrivance and direction of Mr. Graham, his new instrument was fitted up on the 13th of August, 1727. But as he had no convenient place in which he could make use of so long a telescope as Mr. Molineux's, he contented himself with one of about twelve feet and a half in length; judging, from the experience which he had already had, that this radius would be long enough to adjust the instrument to a sufficient degree of exactness: and he had no reason afterwards to change his opinion; for by all his trials he was very well satisfied, that when it was carefully rectified, its situation might be securely depended upon to half a second. And as the place where his instrument was hung, in some measure determined its radius, so did it also the length of the limb, on which the divisions for the adjustment were to be made: for the arc could not conveniently be extended farther than to about six degrees and a quarter, on each side his zenith. This, indeed, was sufficient, since it gave him an opportunity of making choice of several stars, very different both in magnitude and situation; there being more than two hundred inserted in the British catalogue that might be observed with it. It was not necessary, indeed, to have extended the limb so far, but that he was willing to take in Capella, the only star of the first magnitude which came so near his zenith.

His instrument being fixed, he immediately began to observe such stars as he judged most proper to give him some insight into the cause of the motion already mentioned. And as there were not less than twelve that he could observe through all the seasons of the year, it was not long before he perceived, that the notion they had before entertained of the stars being farthest north and south, when the sun was about the equinoxes, was only true of those which were near the solstitial colure. And after he had continued his observations a few months, he discovered what he then apprehended to be a general law, observed by all the stars, namely, that each of them became stationary, or was farthest north or south, when it passed over his zenith at six o'clock, either in the morning or evening. He perceived likewise, that whatever situation the stars were in with respect to the cardinal points of the ecliptic, the apparent motion of all of them tended the same way, when they passed his instrument about the same hour of the day or night; for they all moved southward while they passed in the day, and northward in the night; so that each was farthest north, when it came about six o'clock in the evening, and farthest south, when it came about six in the morning.

He discovered afterwards, however, that the maxima, in most of these stars, did not happen exactly when they passed at those hours; but, not being able, at that time, to ascertain the exact limits, he endeavoured to find what proportion the greatest alterations in declination, of different stars, bore to each other; it being evident, that they did not all change their declination equally.

It was remarked, from Mr. Molineux's observations, that γ Draconis altered its declination about twice as much as the before-mentioned small star almost opposite to it: but examining the matter more particularly, he found, that the greatest alteration in the declination of those stars, was as the sine of the latitude of each respectively; which made him suspect, that there might be the like proportion between the maxima of other stars. Finding, however, that the observations of some of them would not perfectly correspond with such an hypothesis, and not knowing whether the difference he met with might not be owing to some small errors which had escaped his notice, he deferred any farther examination till he should be furnished with a series of observations made in all parts of the year; which might enable him not only to determine what errors they were liable to, but also to judge whether there had been any sensible change in the parts of the instrument itself.

When the year was completed, he began to examine and compare his observations; and having pretty well satisfied himself as to the general laws of the phænomena, he then endeavoured to find the cause of them. He was already convinced, that the apparent motion of the stars was not owing to a nutation of the earth's axis. The next thing that offered itself was an alteration in the direction of the plumb-line, with which the instrument was constantly rectified; but this, upon trial, proved insufficient. He then considered what refraction might do; but here also nothing satisfactory occurred. At last, by a singular sagacity, he conjectured, that all the phænomena, hitherto mentioned, proceeded from the progressive motion of light, and the earth's annual motion in its orbit. For he perceived, that if light was propagated in time, the apparent place of a fixed object would not be the same when the eye is at rest, as when it is moving in any other direction than that of the line passing through the eye and the object; and that, when the eye is moving in different directions, the apparent place of the object would be different.

The means by which we arrive at the knowledge of things, are not less wonderful than the things themselves. A lucky accident often brings truths to light, that abstruse speculation would have never discovered. The curiosity of some children at play produced the telescope; the absurd attempts that have been made to discover the philosopher's stone, have given birth to some of the noblest discoveries in chemistry; and from observations that were designed to determine the parallax of the stars, was obtained a knowledge of their aberration; a circumstance utterly unknown to the astronomers of former ages. Before the time of Roemer, it was the general opinion that the motion of light was instantaneous; or that it was propagated through immense spaces in an instant; but we are now assured, both from observations that have been made on the eclipses of Jupiter's moons, and from the apparent change of place discovered by Dr. Bradley in the fixed stars, that the motion of light, like that of all other bodies, is progressive.

That the aberration of the stars is occasioned by the motion of light may be shown as follows: Let AB (Pl. VIII. fig. 6.) represent a part of the earth's annual orbit, and CB a ray of light, falling from a star perpendicularly upon the line BA: Then if the eye be at rest at B, the object will appear in the direction BC, whether light be propagated in time, or in an instant; but if the eye be moving from A towards B, and light be propagated with a velocity that is to the velocity of the eye, as CB to AB, that particle of it, by which the object will be discerned when the eye comes to B, will be at C when the eye is at A. The star, therefore, will appear in the direction AC; and as the earth moves through the equal parts of its orbit A*a*, *ab*, *bc*, &c. the light, coming from the star, will move through the equal divisions *ci*, *ik*, *kl*, &c. and the star will appear successively in the directions A*e*, *bf*, *cg*, &c. which are parallel to the former AC; so that when the eye comes to B, the object will be seen in the direction BD.

If the line AC be a tube of such a diameter as to admit but one particle of light at a time, it is easy to perceive, that the particle of light at C, by which the object must be seen, when the eye, as it moves along, arrives at B, would pass through the tube AC, if it were inclined to AB, in the angle ABC, and accompanied the eye in its motion from A to B; and that it could not come to the eye through such a tube, if it had any other inclination to the line BD. And the same thing will follow, if, instead of supposing AC to be such a small tube, we imagine it to be the axis of a larger one; for, from what has been said, it is evident, that a particle of light at C cannot pass along that axis, unless it be inclined to BA, in the angle BAC.

Although, therefore, the true or real place of an object be perpendicular to the line in which the eye is moving, yet the visible place must be always in the direction of the tube through which the object is seen; and the difference between the true and apparent place will be greater or less, according to the proportion between the velocity of light and that of the eye. If the earth revolves round the sun annually, and the velocity of light be to the velocity of the earth's motion in its orbit, as one thousand to one, it may be proved, by a trigonometrical process, that the apparent place of the object, from which the light proceeds, will constantly differ from the true place by about three minutes and an half; so that a star, placed in the pole of the ecliptic, would seem to describe a circle round that pole, the diameter of which would be seven minutes.

From a number of observations, made by Dr. Bradley upon the same stars for three years, he found, that their apparent places differed from their true places by about twenty seconds; by which means it is proved, that the velocity of light is about ten thousand three hundred and ten times greater than the velocity of the earth in her orbit. But the velocity of the earth is about fifty-eight thousand miles an hour, and therefore light will pass from the sun to the earth, or through ninety-three millions of miles, in eight minutes and seven seconds; and as this is nearly the same as the time discovered by Roemer, and was deduced from a different phænomenon, which was owing to the same cause, they mutually confirm each other; and the progressive motion of light is now proved in a manner that admits of no objection.

But this is not the only advantage arising from Bradley's discovery; the aberration of the stars being a direct proof of the motion of the earth in its orbit, and a new confirmation of the truth of the Copernican system. This system, indeed, is the basis of most of the great discoveries of Newton; and to those who can follow that sublime philosopher through all his calculations and enquiries, the

Copernican hypothesis will want no other support than what he has given it: but this evidence is confined principally to men of science, who have entered into the depth of mathematical investigations, and are qualified to judge of their validity. There are minds that require proofs more immediate and sensible, who judge of probability, not from calculations but from facts; and with these the observations of Bradley ought to have great weight. He has discovered, that the motion of light, combined with the motion of the earth, produces an apparent difference in the places of the fixed stars; and as this motion is found to affect all the stars differently, according to their situations, such a similarity of variations is sufficient to justify the truth of the cause upon which they were supposed to depend, and to show that the system of the world, as restored by Copernicus, is conformable to nature and the order of things.

LETTER XX.

OF THE CONSTELLATIONS, AND THE PHÆNOMENA OF THE FIXED STARS.

THE heavens are divided by astronomers into three regions, called the northern and southern hemispheres, and the zodiac; and in order that the fixed stars may be treated of according to their true positions and situations, they have been classed under the outlines of certain imaginary figures of birds, beasts and other animals; which are called Constellations. The number of these, in the northern hemisphere, is thirty-six; in the southern thirty-two; and in the zodiac twelve: and as there are some stars that admit of no regular arrangement, they are called unformed stars; and others, from their cloudy appearance, are comprised under the name of Nebulæ.

This division of the starry firmament into Constellations, is of the highest antiquity. Bootes and the Bear are spoken of both by Homer and Hesiod; Arcturus, Orion, and the Pleiades, are mentioned in the book of Job; and there is scarcely any ancient author in which the names of some of the most remarkable ones are not to be found. But to trace the origin of this invention, and to show why one animal had the honour of being advanced to heaven in preference to another, is no easy task. M. Fréret, the Abbe la Pluche, and several other writers of considerable eminence, have ransacked all the legends of fabulous history for the illustration of this subject; but, except in a few obvious instances, no consistent and satisfactory account has yet been given.

Most of the memorable events and customs of ancient times were involved in obscure hieroglyphical representations; and many of the constellations are probably symbols of this kind. The division of the zodiac into twelve signs, of thirty degrees each, has a manifest relation to the twelve months of the year; and the animals, by which those signs are denoted, were perhaps designed as emblems of the different productions of nature, in those seasons over which they preside; or as indicating certain circumstances relating to the motion of the sun in the heavens. Many of the constellations also appear to have been formed in honour of certain heroes and celebrated personages, whose memory they were meant to perpetuate; and any vague resemblance of a crown, a cross, or a triangle, would occasion the parts of the heavens where they were found to be called by those names. This manner of classing the stars is indeed so natural, that it is found among the Chinese, the Americans, and many other nations that seem to have had no intercourse with the rest of the world.

The heavens being thus divided, it was more easy to reduce the stars into order, and to determine their number, than it would have been without such a contrivance. And though this be considered, by the uninstructed part of mankind, as an impossible thing, it has been often attempted both by the ancients and moderns. Hipparchus the Rhodian, who lived about 120 years before Christ, was the first among the Greeks that engaged in this singular enterprize; "daring (according to Pliny) to undertake a thing which seemed to surpass the power of a divinity; that is, to number the stars, and to ascertain their true places in the heavens." It was imagined in those days, as it is at present, that, in a fine winter's night, when the sky is perfectly clear, the stars which may be seen in the firmament are beyond the reach of all calculation; and that

> "To count their numbers, were to count the sands
> That ride in whirlwinds the parch'd Libyan air;
> Or waves that, when the blustering north embroils
> The Baltic, thunder on the German shore."
>
> ARMSTRONG.

This, however, is a mistaken notion: the number of stars, as I have observed in a former letter, that can be seen by the naked eye in the whole visible hemisphere, is not much above a thousand. Hipparchus, from his own observations, and those of the ancients that preceded him, inserted in his catalogue only one thousand and twenty-two, annexing to each of them the latitude and longitude which they had at that time. Ptolemy added four to this number; and others were afterwards discovered by different astronomers, who applied themselves to this subject. But of all the catalogues of the stars which have hitherto been made, that which is given by Flamsteed, in his Historia Cœlestis, and the one lately published by Bode, are the most complete. The number of stars inserted in the former of these catalogues is about three thousand; which number has been since augmented to near five thousand, by Halley, La Caille, Le Monnier, and others; and from the accuracy of their observations, there is scarcely a star to be seen in the heavens, whose place and situation is not better known than that of most cities and towns upon the earth.

And in order that the memory may not be burthened with a multiplicity of names, astronomers mark the stars of every constellation with a letter of the Greek alphabet; denoting those that are the most conspicuous by α, the next by β, and so on in succession; by which means they can be spoken of with as much ease as if each had a separate name. This was the invention of John Bayer, a native of Augsburg, in Germany, who first introduced it about the year 1603, in his charts of the constellations. But the best works of this kind, that have yet been executed for representing the constellations, and the stars of which they are composed, are the Atlas Cœlestis of Flamsteed, and Bode's Atlas before-mentioned; which, together with the stars discovered by La Caille in the southern hemisphere, contain an entire map of the heavens; so that by means of these charts, or a good celestial globe, we can easily know any particular star which is discernible to the eye, and tell the constellation to which it belongs.

The names of the constellations, and the manner of denoting some of the principal stars of the first and second magnitude, may be seen in the following Table; in which it may be observed, that the stars marked β, γ, &c. are not the most conspicuous, in the constellations to which they belong, but were chosen on account of their places being better settled, or from some other remarkable circumstance attending them.

CONSTELLATIONS IN THE ZODIAC.

Constel.		Stars.	Mag.	Constellat.	Marks.	Stars.	Mag.
Aries	♈	α Arietis	2	Libra	♎	α Libræ	2
Taurus	♉	Aldebaran	1	Scorpio	♏	Antares	1
Gemini	♊	Castor and Pollux	1.1	Sagittarius	♐	ε Sagittarii	2
Cancer	♋	. . . .		Capricornus	♑	. . . .	
Leo	♌	Regulus	1	Aquarius	♒	. . . .	
Virgo	♍	Spica Virginis	1	Pisces	♓	. . . .	

NORTHERN CONSTELLATIONS.

Constellations.	Stars.	Mag.	Constellations.	Stars.	Mag.
Ursa Major	α Ursæ Majoris	2	Camelopardus	. . . . .	
Ursa Minor	α Urs. Min. P. S.	2.3	Serpens	α Serpentis	2
Draco	γ Draconis	2	Ophiuchus	α Ophiuchi	2
Cepheus	. . . .		Scutum	. . . . .	
Canes Venatici	. . . .		Aquila	Atair	1
Bootes	Arcturus	1	Antinous	. . . . .	
Mons Menalus	. . . .		Delphinus	. . . . .	
Coma Berenices	. . . .		Equulus	. . . . .	
Cor Caroli	. . . .		Sagitta	. . . . .	
Corona Borealis	α Coronæ Boreal.	2	Andromeda	β Andromedæ	2
Hercules	α Herculis	2.3	Perseus	β Persei, Algol	2
Cerberus	. . . .		Pegasus	γ Peg. Algenib	2
Lyra	α Lyræ	1	Auriga	Capella	1
Cygnus	α Cygni	2	Lynx	. . . . .	
Vulpecula	. . . .		Leo Minor	δ Leonis Min.	2.3
Anser	. . . .		Triangulum	. . . . .	
Lacerta	. . . .		. . . .	. . . . .	
Cassiopeia	β Cassiopeiæ	2	Musca	. . . . .	

SOUTHERN CONSTELLATIONS.

Constellations.	Stars.	Mag.	Constellations.	Stars.	Mag.
Cetus	α Ceti	2	Pavo	α Pavonis	2
Eridanus	Achernar	1	Corona Aust.	. . . . .	
Phœnix	α Phœnicis	2.3	Grus	α Gruis	2
Toucan	. . . . .		Piscis Aust.	Fomalhaut	1
Orion	Rigel	1	Lenus	. . . . .	
Monoceros	. . . . .		Columba	α Columbæ	2
Canis Minor	Procyon	1	Robur Caroli.	. . . . .	
Apus	. . . . .		Crux	α Crucis	1
Hydra	α Hydræ	2	Argo Navis	Canopus	1
Sextans	. . . . .		Canjs Major	Sirius	1
Crater	. . . . .		Apis	. . . . .	
Corvus	. . . . .		Hirundo	. . . . .	
Centaurus	α Centauri	1	Indus	. . . . .	
Lupus	. . . . .		Chamelion	. . . . .	
Ara	. . . . .		Piscis Volans	. . . . .	
Triangulum	α Trianguli	2.3	Xiphias	. . . . .	

These, as well as most of the other principal stars in the several constellations, may be readily known by means of a common celestial globe; which being rectified for the latitude of the place, day of the month, and time of the night, the stars which you will find marked upon different parts of its surface, will be directly under those of the same name with them in the heavens; and consequently will be easily found and remembered upon any other occasion. But as a celestial globe may not always be at hand, I have presented you with a simple unembarrassed scheme (Pl. XIV.), of the northern hemisphere, which in many cases may answer the same purpose. It is divested of the figures of the constellations with which it is usually embellished; and only the principal stars have been retained, towards which your attention will of course be more particularly directed.

Those stars that are connected by dotted lines belong to the same constellation, the names of which are written in small Roman characters, in order to distinguish them from the names of the principal stars in the same, which are given in Italics. The plain lines which are drawn connecting some of the larger stars, are merely to show their position with regard to each other; and by means of the figures that are thus formed, as triangles, squares, &c. you will, with a little attention, be able to distinguish them, when they are referred to the heavens.

The most remarkable constellation in the northern hemisphere, and that which is more generally known, is the Great Bear; which consists of seven principal stars, four of which form nearly a square, and of these, the two hindermost are called the pointers; because, if you imagine a line to be drawn through them and continued upwards, the first large bright star which it nearly passes through, is the polar star.

Having thus got the north star, and the seven in the Great Bear, observe what figures they form with some other remarkable star; then by referring to your map, and tracing out there, by your eye, the same figure, you will find the name of this star, which let us suppose to be Arcturus; then again proceed with this and some other in the same manner, and you will soon become familiar with the names of most of the constellations, and the principal stars they contain.

But of all the phænomena of nature, the sudden appearance of new stars, and the disappearance of old ones, is one of the most singular, and difficult to be accounted for. A circumstance of this kind first led Hipparchus to compose his catalogue of the stars, in order that posterity might be apprized of the true state of the heavens at that period; and since his time many changes of the same nature have been observed, both by ancient and modern astronomers. Some of the larger stars have not the same precise situations which are attributed to them by the ancients, and others are found to have a periodical increase and decrease of magnitude. The bright stars, Sirius and Arcturus, have been observed to change their places, by moving towards the south, about two or three minutes of a degree in a century; and the stars, Aldebaran and Aquila, have also a like motion, but something slower, and less easy to be determined.

Among the new stars which have been discovered by the moderns, that which appeared on the 8th of November, in the year 1572, was the most remarkable. Its splendor exceeded that of Jupiter when nearest the earth, and was such that it could be seen in the day-time. Cornelius Gemma first observed it in that part of the heavens which is called Cassiopeia's Chair, forming a perfect rhombus with the three stars α, β and γ, of that constellation; and Tycho Brahe, who saw it on the

11th of the same month, found its longitude to be six degrees fifty-four minutes of Taurus, and its latitude fifty-three degrees forty-five minutes north. About the beginning of December it began to diminish, becoming gradually less and less till the month of March 1574, when it totally disappeared, and has never been seen since. It was found to have no parallax, nor any apparent motion, and was sparkling and clear like the rest of the fixed stars.

On the 10th of October 1604, the scholars of Kepler discovered another new star in the right leg of Serpentarius, which was nearly as brilliant as the former. Its right ascension, as observed by Kepler, was constantly two hundred and fifty-six degrees fifty-seven minutes, and its declination twenty-one degrees one minute and a half south. This star, also, had no parallax, nor any apparent motion; and after suffering a gradual diminution of its light, it totally disappeared about the beginning of January 1606. Neither of these stars had any tail, to countenance an idea of their being comets; and as they had no parallax, it is evident that they must have been at a greater distance from the earth than any of the planets.

The first star that was observed to have a periodical change of brightness is that marked *o* by Bayer, in the neck of the Whale. It was discovered by David Fabricius on the 13th of August, 1596. At the time of its greatest brightness, it appears equal to a star of the third magnitude; and is scarcely ever so small but that it may be seen with a six feet telescope. Hevelius assures us, that it once entirely disappeared for four years; and Cassini, who observed it at the time of its greatest splendor, about the beginning of August 1703, found it to be of the third magnitude, as had before been supposed by Fabricius. In this time it had made about one hundred and seventeen revolutions, which, at a mean, fixes its period at three hundred and thirty-four days; but it has since been found that its changes are very irregular.

Three changeable stars have also been observed in the neck of the Swan. The first is that near the star γ in that constellation. Its greatest lustre is less than that of one of the third magnitude, and it gradually diminishes till it is equal to one of the sixth. Its changes are also far from being regular, and do not recur till after an interval of ten or more years. The next is that marked χ; which is more regular in its returns than the former, though its magnitude is seldom greater than that of one of the sixth, and its period is settled at about four hundred and five days. The third was seen near the head of the Swan, on the 20th of June 1670, and appeared of the third magnitude, but was so far diminished in October following, as to be scarcely visible. In the beginning of April 1761, it was again seen, rather brighter than before; and after several other changes, by which its period was judged to be about ten years, it disappeared on the 30th of March 1762, and has not been seen since.

The star Algol, or Medusa's head, has been long since observed to appear of different magnitudes at different times; but the discovery of its period is due to John Goodricke, Esq. of York, who first began to observe it about the beginning of the year 1783. It changes continually from the first to the fourth magnitude; and the time employed from its greatest diminution to its least, is found, at a mean, to be two days, twenty hours, forty-nine minutes and three seconds. The change is thus: during four hours, it gradually diminishes in lustre; and in the succeeding four hours it regularly recovers its first magnitude. In the remaining part of the period it invariably preserves its greatest lustre; and after the expiration of this term the diminution again commences.

Many opinions have been entertained concerning the cause of these phænomena, but as they are frequently incongruous and unsatisfactory, I shall only give you a few of the most plausible. If the light of the sun and stars be owing to a combustion similar to that which is required to produce light in most other substances, it will follow, that when the inflammable matter is decomposed, the ignition will cease. Or, if a mass of combustible matter begin by any cause to burn, its ignition and emission of light will commence at the same time. So that if these considerations be applied to the fixed stars, the appearance of some, and the disappearance of others, will be rationally accounted for; and as there are no data by which their periods can be ascertained, they may last any given time according to circumstances.

The spots on the sun have also afforded a conjecture concerning the cause of a periodical change of brightness in some of the fixed stars. For if a star be supposed to turn upon its axis, and to have a spot of considerable magnitude upon some part of its surface, it will appear much brighter when the spot is not on the visible disc, than when it is wholly exposed to our sight; and as it is more or less seen, an alteration of light will take place accordingly. But against this hypothesis it must be observed, that the phænomena in general do not agree with the supposition; for the brightness or obscurity which prevails in some of the changeable stars for more than half their periods, seems to prove that their different appearances cannot be owing to a defalcation of light on any part of their surfaces.

Another conjecture, which appears something more probable, is, that if a star, by a swift revolution, be made to assume and preserve a flattened figure, and its axis have a rotation similar to that of the earth, it will be much less bright when its edge is presented to the observer, than when the visible disc is projected broader. Or, lastly, if a planet be supposed to revolve round a star, in the same manner as the planets in our system revolve round the sun, it may occasion certain periodical eclipses, of such magnitudes and durations, as are sufficient to account for all the changes in its appearance. Thus, for instance, if an opaque planet, whose diameter is not much less than that of Algol, be supposed to revolve about that star, in a plane whose orbit passes through the earth, it will occasion certain eclipses, which, by supposing its period and distance to be properly regulated, may be made to agree with all the observed appearances.

Several other changes in particular stars have been observed by different astronomers, but as they are less conspicuous I shall pass them over in silence. Many of the fixed stars have also been found to consist of two, or to appear as if they were double. The number of these was formerly thought to be very small; but Herschel, who stands unrivalled for the excellence of his instruments and his skill in using them, has discovered upwards of four hundred.

Besides these, there are also many nebulæ, or parts of the heavens which appear brighter than the rest. One of the most obvious to common notice is that large irregular zone, or band of light, which crosses the ecliptic in Cancer and Capricorn, and is inclined to it in an angle of about sixty degrees. Other nebulæ are seldom to be distinguished by the eye from small stars; but if the telescope be applied to them, they seem to be luminous spots of various figures, and in some instances with stars in them. One of the most curious of these is in the belt of Orion; the figure of which as seen by a good telescope is shown in (Pl. XVII.) The number of nebulæ was formerly imagined to be about one hundred and three; but Herschel, previous to the month of April 1784, had discovered four hundred and sixty-six more. Many of these are resolvable by the telescope into clusters of small stars; and telescopes of a still greater power resolve those nebulæ into stars, which, in instruments of less force, appear like white clouds; so that there is great reason to conclude that they all consist of clusters or large masses of stars, at a prodigious distance from our system.

Herschel is of opinion, that the starry heaven is replete with these nebulæ, and that each of them is a distinct and separate system, independent of the rest. The milky-way he supposes to be that particular nebula in which our sun is placed; and in order to account for the appearance it exhibits, he supposes its figure to be much more extended towards the apparent zone of illumination than in any other direction; which is a supposition that he thinks allowable, from the observations he has made on the figures of other nebulæ of the like kind. These are certainly grand ideas, and, whether true or not, do honour to the mind that conceived them.

This notion, indeed, of forming the stars into systems, is not a new one. The ingenious Mr. Michell, about sixty years ago, had the same idea. He observed that there were many large spaces in the heavens where no stars are to be seen; and others in which a number of very considerable ones appear near together, in the midst of several smaller ones. The Pleiades, for instance, are composed of six remarkable stars, which are placed in the midst of a number of others, that are all between the third and sixth magnitude; and as there are only about one thousand five hundred stars in the whole heavens, which are visible to the naked eye, he calculated, by the doctrine of chances, that among all this number, if they had been dispersed arbitrarily through the celestial vault, it was five hundred million to one, that six of them should be placed together in so small a space.

It is therefore so many chances to one that this distribution was the work of design, or that there is a reason or cause for such an assemblage; and in a universe where every thing is governed by immutable laws, this degree of probability is exceedingly strong. The stars, therefore, which are thus grouped, (Pl. xv.) are most probably systems analagous to the solar one; and our sun, which appears to be the lord of the universe, is most likely only a star that belongs to one of those systems that are interspersed through the regions of the infinite expanse. This is conformable to the designs of Nature in all her operations. Our planetary system demonstrates, that she unites and connects several bodies together in order to compose a whole; and it is highly probable, that all her works are conducted upon the same plan.

But a necessary consequence of this idea is, that these different systems should be mutually balanced among themselves by some general cause; and this is most probably effected by means of one system, which regulates the others by the number of bodies it contains; or perhaps by one body, which is more powerful than all the rest, and round which they all move. Here then is a gradation in the most magnificent works of nature, like that which we perceive among the lower orders of existences. The satellites accompany the planets; the planets follow the sun; and the sun himself is connected with a system of stars, over which presides another sun of superior magnitude and force; and so on, through a number of variations and degrees, which not even the imagination itself can trace.

The immense distance of these vast bodies, is also another consideration that overpowers all our faculties. James Cassini attempted to show, that the annual parallax of Sirius, which is the nearest of all the fixed stars, is about six seconds; and from this it would follow, that its distance from our earth is near eighteen thousand times greater than that of the sun. But from all the observations hitherto made, it appears, that the parallax of the stars is altogether insensible, and consequently their distance must be such that no calculation can estimate. If the stars, therefore, be considered as suns, having a number of planets moving round them, like those that compose the solar system, it will be no argument against their existence, to say that we do not see them; for as the suns themselves are at such distances as to appear like so many luminous points, the planets, which shine only by reflection, must be totally invisible.

Dr. Halley has a very ingenious observation upon the magnitudes and distances of the fixed stars. He remarks, that there can be only thirteen points upon the surface of a sphere, whose distances from each other shall be all equal to the radius; and as the nearest fixed stars are generally considered to be as far from each other as they are from the sun, he supposes them to be placed in the surface of an imaginary concave sphere, which has the sun for its centre; and thence infers, that there can be only thirteen stars of the first magnitude. The stars of the second magnitude he supposes to be twice as far distant from the sun as those of the first, and by placing them in like manner in the surface of a sphere, at such distances from each other as are equal to half the radius, their number will be fifty-two. At a triple distance the surface of a sphere would contain an hundred and seventeen, which, therefore, is the number of stars of the third magnitude; and so on. This supposition is nearly agreeable to the usual method of classing the stars of the first and second magnitude; and if the distribution of them could be made according to their true magnitudes, it would probably be found more accurate.

Halley conceived the whole solar system, together with all the systems of the stars, to be in motion round some point, which is the centre of gravity of the whole; and in pursuing this idea, the following reflections naturally occurred to him: "If," says he, "the number of stars be finite, and occupy only a part of space, it will follow that they must be surrounded by a void. But as this void can have no action upon the bodies which it environs, those bodies must exert all their force upon one another, without equilibrium, and without compensation. Those which are at the extremities, or near the borders of the void, will be strongly and continually attracted by those near the centre; and these efforts, continued and multiplied through a number of ages, must at length draw all the suns and planets into that point, and form one immense mass, which must for ever remain there, without action and without motion. But if, on the contrary, the number of stars be infinite, and the system without bounds, all the forces will be balanced among themselves; the suns and planets will preserve the paths prescribed them; and the order of the universe will be perpetually the same." These are the conceptions of a vigorous mind; but they lead us into a labyrinth where there is no clue to be found; infinity can be comprehended by God alone.

LETTER XXI.

OF THE PHÆNOMENA AND AFFECTIONS OF THE SUN, MOON, AND PLANETS.

The sun was generally considered by the ancients as a globe of pure fire; but, from a number of dark spots, which, by means of a telescope, may be seen on different parts of his surface, it appears that this opinion was ill-founded. These spots consist, in general, of a nucleus, or central part, which appears much darker than the rest, and seems to be surrounded by a mist or smoke; and they are so changeable in their situation and figure, as frequently to vary during the time of observation. Some of the largest of them, which are found to exceed the bulk of our earth, are often to be seen for three months together; and when they disappear, they are generally converted into faculæ, or luminous spots, which appear much brighter than the rest of the sun. About the time that they were first discovered by Galileo, forty or fifty of them might be frequently seen on the sun at a time; but at present we can seldom observe more than thirty; and there have been periods of seven or eight years, in which none could be seen.

Father Scheiner, who was contemporary with Galileo, has given us an anecdote, which will serve to show how this discovery was at first received. He imagined himself to have been the only person who had ever seen this curious phænomenon, and having communicated the result of his observations to the provincial of his order, received the following answer. "This subject is not mentioned by any of the ancient philosophers: I have read my Aristotle several times over, and have found nothing like what you speak of. Do not expose yourself by propagating these absurdities; for be assured, that it is only some defect in your eyes or your glasses, which makes you imagine that you see spots in the sun." And so firmly persuaded was this zealous Peripatetic that every thing was contained in the Greek philosophy, that neither the most rational arguments, nor the evidence of his senses, could convince him to the contrary: he continued inflexible in his opinion, and would not suffer Scheiner to publish his discovery, till he had promised him to do it under a fictitious name.

The general opinion concerning the solar spots is, that they are occasioned by the smoke and opaque matter thrown out by volcanos or burning mountains of immense magnitude; and that when the eruption is nearly ended, and the smoke dissipated, the fierce flames are exposed, and appear like faculæ or luminous spots. Lahire imagined the sun to be in a continual state of fusion, and that the spots which we observe are only the eminences of large masses of opaque matter, which, by the irregular agitations of the fluid, sometimes swim upon the surface, and at other times sink and disappear. Others have supposed them to be occasioned by a number of planets, circulating round the sun, at a small distance from his surface.

But Dr. Alexander Wilson, of Glasgow, has attempted to prove, from observation, that most, if not all the spots, are excavations in the luminous matter that environs the sun's body, and which is probably of no great depth.

The motion of the spots is from east to west; and as they are observed to move quicker when they are near the central regions, than when they are near the limb, it follows that the sun must be a spherical body, and that he revolves on his axis in a contrary direction, or from west to east. The time in which he performs this revolution, as observed by Cassini, is twenty-five days, fourteen hours and eight minutes; and from the line of the motion of the spots, which is sometimes straight, but oftener crooked or elliptical, it is discovered that his axis is not perpendicular to the plane of the ecliptic, but inclined to it so as to make an angle with the perpendicular of about seven degrees and a half.

The zodiacal light is another singular phænomenon, which accompanies the sun, and is usually attributed to his atmosphere. It begins to appear a little before sun-rise, and seems, at first sight, like a faint whitish zone of light, resembling the milky-way, with its borders ill terminated, and scarcely to be distinguished from the twilight, which is seen commencing near the horizon. It is then but little elevated, and its figure nearly agrees with that of a flat lenticular spheroid, seen in profile. As it rises above the horizon it becomes brighter and larger to a certain point, after which the approach of day renders it gradually less apparent, till it becomes quite invisible. The direction of its longer apparent axis is observed to be in the plane of the sun's equator; but its length is subject to great variations, so that the distance of its summit from the sun varies from forty-five to one hundred and twenty degrees.

But of all the discoveries which have been made by means of the telescope, those relating to the moon are the most curious and interesting. This planet being much nearer to us than any of the rest, is the first that offers herself to our inspection, and is the best adapted for examination. By viewing her with the naked eye we discern a number of spots, which the imagination naturally supposes to be seas, continents, and the like; and on a more accurate inspection, with a telescope, the hypothesis of planetary worlds receives additional confirmation. Vast cavities and asperities are observed upon various parts of her surface, exactly resembling valleys and mountains; and every other appearance seems to indicate, that she is a body of the same nature with our earth. We can scarcely hope to make optical instruments sufficiently perfect to render animals visible at such a distance; but Herschel, whose telescopes are far superior to any that were ever before executed, is said to have discovered a manifest volcano in the moon; and if his improvements are pursued, we may, perhaps, receive indubitable proofs of her being an inhabited world.

Galileo, when he first saw this planet through his telescope, was struck with the singularity of her appearance; and being free from the prejudices of the schools, soon discovered a striking similitude between her and the earth. This is what Milton finely alludes to when he describes the shield of Satan, in the first book of his Paradise Lost.

> ——————" The broad circumference
> Hung on his shoulders like the moon, whose orb
> Through optic glass the Tuscan artist views,
> At evening from the top of Fesolé,
> Or in Valdarno, to descry new lands,
> Rivers or mountains in her spotty globe."

Several astronomers have given us exact maps of the moon, with the figure of every spot, as it appears through the best telescopes, (Pl. XVI.) distinguishing each of them by a proper name. Riccioli divided the lunar regions among those philosophers and astronomers, who have distinguished themselves by advancing the knowledge of the heavens, giving the names of the most celebrated characters to the largest spots, and those of less eminence to the smaller. But Hevelius, who did not approve of this distribution, denoted the different parts of the moon by such geographical names as belong to the several islands, countries, and seas of our earth, without any regard to their situation or figure. The method of Riccioli, however, is that which is now generally followed, as the names of Hipparchus, Tycho, Copernicus, &c. are more pleasing to astronomers, than those of Africa, the Mediterranean Sea, Sicily and Mount Ætna.

That the spots in the moon, which are taken for mountains and valleys, are in reality such, is evident from their shadows. For in all situations of the moon, the elevated parts are constantly found to cast a triangular shadow, in a direction opposite to that of the sun; and, on the contrary, the cavities are always dark on the side next the sun, and illuminated on the opposite one; which is exactly conformable to what we observe of hills and valleys on the earth. And as the tops of these mountains are considerably elevated above the other parts of the surface, they are frequently illuminated when they are at a considerable distance from the confines of the enlightened hemisphere, and by this means afford us a method of determining their heights.

Thus, let EGD (Pl. x. fig. 5.) be the moon's enlightened hemisphere, ECD the diameter of the circle bounding light and darkness, and A the top of a mountain when it first begins to be illuminated: Then, since the ray of light SEA is a tangent to the moon at the point A, the angle CEA will be a right angle; the line AE, or the distance of the point A from the boundary ECD, can also be measured by means of a micrometer; and CE is the known radius of the moon. We have therefore the two sides CE and EA, of the right-angled triangle CEA, whence we can find the third side CA; and subducting the radius CB, the remainder AB will be the height of the mountain required. Riccioli observed the top of the hill called St. Catherine, upon the fourth day after the new moon, to be illuminated when it was distant from the confines of the enlightened hemisphere about one-sixteenth part of the moon's diameter; and by this means found its height to be nine miles: But Herschel, and others, since telescopes have been brought to their present degree of perfection, have found that the height of the lunar mountains are much over-rated, and have shown, that few of them exceed one half or three quarters of a mile in height.

Astronomers were formerly of opinion that the moon had no atmosphere, because she is never obscured by clouds or vapours, and because the fixed stars, at the time of an occultation, disappear instantaneously, without any gradual diminution of their light. But if we consider the effects of days and nights, which are near thirty times as long as with us, we may readily grant that the phænomena of vapours and meteors must be very different. And besides, the vaporous or obscure part of our atmosphere is only about the one thousand nine hundred and eightieth part of the earth's diameter, as is evident from the height of the clouds, which is seldom above three or four miles; and, therefore, as the moon's apparent diameter is only about thirty-one minutes and a half, or one thousand eight hundred and ninety seconds, the obscure part of her atmosphere, supposing it to resemble our own, when viewed from the earth, must subtend an angle of less than one second;

which is so small a space, that observations must be extremely accurate to determine whether the supposed obscuration takes place or not.(*q*)

In looking at the moon through a telescope, we constantly observe the same face; from which it is evident that she turns only once round upon her axis in the time of every periodical revolution; so that the inhabitants of the moon have but one day and night in the course of a month. This rotation on her axis, which is the most uniform motion the moon has, occasions a seeming irregularity, which is called her libration: for as the moon's motion in her orbit is not uniform, the effect it has in turning her face from the earth is likewise subject to the same irregularities; so that, for instance, in the swiftest part of her revolution, her face is turned from the earth something more than her rotation on her axis turns it the contrary way; and therefore she will appear to have a small motion on her axis towards the east.

In the slower part of her revolution, the contrary will be seen; for then the rotation on her axis prevailing, brings the western parts into sight, and occasions the eastern to disappear. This is called libration in longitude; besides which there

(*q*) Notwithstanding what is here advanced, however, Schroeter, an eminent German astronomer, is said to have ascertained that such obscuration really takes place, and hence he not only infers the existence of an atmosphere, but has also estimated the height of it; which, according to him, does not exceed four or five miles.

is another kind of libration, that arises from the moon's axis being inclined to the plane of her orbit; on which account, sometimes one of her poles, and sometimes the other, is inclined towards the earth. In consequence of this we see more or less of the polar regions at different times, and therefore this motion is called libration in latitude.

One of the most remarkable phænomena attending the moon, is the continual change of figure to which she is subject. Sometimes she appears perfectly full, or circular, at other times only half or a quarter illuminated, changing through a great variety of shapes. And as these changes are always the same at the same elongation from the sun, they prove that she receives her light from that luminary: for the moon being enlightened on that side only which faces the sun, a greater or less quantity of that enlightened part will be visible, according as it is turned towards us, or from us; and her figure will consequently appear to vary through the whole of her revolution. This may be easily illustrated by means of an ivory ball; which being held before a candle in various positions, will present a greater or less portion of its illuminated hemisphere to the view of the observer, according to its situation.

The same thing may also be shown thus: Let S (Pl. XVIII.) represent the sun, T the earth, A, B, C, D, &c. the moon's orbit: then when the moon is at A, in conjunction with the sun S, her dark side being entirely turned towards the earth, she will disappear, as at *a*, and is now called the new moon. When she comes to her first octant at B, or has gone through an eighth part of her orbit, a quarter of her enlightened hemisphere will be turned towards the earth, and she will then appear horned, as at *b*. When she is at C, or has gone through a quarter of her orbit, she shows us one half of her enlightened hemisphere, as at *c*, and is then said to be a quarter old. At D she is in her second octant, and by showing us more of her enlightened hemisphere than at C, she appears gibbous, as at *d*. At E, her whole enlightened side is turned towards the earth, and now she appears round, as at *e*, and is said to be at her full. In her third octant at F, part of her dark side being turned towards the earth, she again appears gibbous, and is on the decrease, as at *f*. At G we see just one-half of her enlightened side, at which time she appears still farther decreased, as at *g*. When she comes to her fourth octant at H, we only see a quarter of her enlightened hemisphere, which occasions her to appear horned, as at *h*. And at A, having now completed her course, she again disappears, or becomes a new moon as before.

Another remarkable circumstance, or appearance, relating to this body, is what is usually termed the Harvest Moon.

In general this luminary, by revolving about the earth in the course of one lunation from west to east, that is, in the same direction as the diurnal rotation of the latter body is performed, advances every day about twelve degrees forward in her orbit. And, therefore, supposing the moon to rise with any fixed star on one night, the next night when the same star appears, the moon will be about twelve degrees below the horizon; and, consequently, will not rise so soon as the star with which she rose the preceding night, by about fifty minutes.

This at least would always be the case if the moon's orbit were in the plane of the equator; but as it is nearly in that of the ecliptic, and different portions of this circle rising in the same time, according to the degree of obliquity which it makes with the horizon of any place, it follows, that the moon will rise with a greater or less difference of time, on any two successive nights, according as the ecliptic and horizon form a greater or less angle with each other.

And since this angle is always the least when the moon is in the sign Aries, where the ecliptic cuts the equator, it will, at that time, rise with a less difference of time than in any other part of her orbit; and as she is also at the full, in the autumnal quarter, when in this sign, it follows, that the full moon which happens at this season, will rise almost immediately after the sun sets, for several nights together, and is therefore generally called the harvest moon; the advantage of which to the husbandman, in gathering in the fruits of the earth, was for a long time better understood than the physical cause from which this advantage was derived.

In southern latitudes the same thing happens when the moon is in the opposite sign Libra; which being the harvest season in those climates, renders it equally serviceable in the southern as in the northern hemisphere.

Thus we perceive the great directing hand of the Deity in every operation of nature; wisdom and design are seen in all his works; every phænomenon of the heavens displays intelligence and art; and raises in our minds the most exalted ideas of the wisdom, power and beneficence, of the great Creator and Director of the whole.

In order to illustrate this phænomenon by a figure; let P′P (Pl. VIII. fig. 4.) represent the axis of the world; QU the equator at right angles to the same; EC the ecliptic, in which, for the present, we will suppose the moon's motion to be performed; and HO the horizon of any place in north latitude, in which the rising and setting of all the celestial bodies are observed. Let also A be the first point of Aries, where the ecliptic cuts the equator, and A*m*C the order of the signs, or the direction of the moon's motion in her orbit. Then if we suppose this luminary to rise at A on any one night, the next night, at the same time, she will be advanced in her orbit to *m;* therefore, it is evident, that the smaller the angle OAC is, the sooner after that time, will she be seen in the horizon HO; because the motion of the sphere is made about P′P.

It is also obvious, that the higher the latitude of the place is, or the more the point P is elevated, the less will be the difference in the time of her rising on any two successive nights; because the angle OAC will thus become less and less. Consequently if the pole were elevated till EC coincided with HO, she would then rise on any night at the same hour that she rose the night before; as is the case in latitude sixty-one degrees twenty-three minutes north; and if it were still more elevated, so that E fell below H, then she would rise earlier each night than she did on the preceding night; which is actually the case in all places whose latitude is greater than sixty-one degrees twenty-three minutes.

At present we have supposed the moon to move in the plane of the ecliptic, but this is not precisely the case; for her orbit is inclined to that circle at an angle of five degrees nine minutes; and, therefore, instead of her motion being in AC, it is really performed in HZ (Pl. VIII. fig. 5.); and therefore the angle OAC, is reduced to OAZ; and consequently the effect which has been already explained on the former supposition, will be still more strongly marked by the decrease of the angle between the horizon and the plane of the moon's orbit.

I have already observed, that this happens every time the moon is in the sign Aries; but it is little noticed except in the autumnal quarter; because it is only at that period that the moon is at the full when she is in this sign. In the latitude of London, the difference in the time of rising of the full moon at this period, is about twenty minutes, and therefore for six days together there is only a variation of two hours; whereas, at any other season, there would be a variation of five hours; the daily difference of rising being in that case about fifty minutes: which circumstance enables the husbandman to employ the time that is so precious to him at this season, to the greatest possible advantage, either by cutting his corn, or carrying that which has been already prepared by the meridian heat of the preceding day's sun.

The horizontal moon is another remarkable phænomenon attending this luminary, that it may be proper to notice; by which is to be understood its apparent increase of magnitude when in the horizon. Every one must have observed, that the diameter of the moon when she rises or sets, always appears considerably greater than when she is more elevated; whereas, as she is really farther from us in the former case, than in the latter, she ought from the principles of optics to appear less.(*r*) Various hypotheses have been advanced to account for this phænomenon; some attributing it to the faintness of the light by which she is then visible; which gives us an idea of her being at a greater distance; because we always judge of the magnitude of bodies by means of the

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(*r*) That the moon is farther from us when seen in the horizon, than when near the zenith may be shown thus: Let BAC (Pl. 9. fig. 2.) represent the earth, M the moon in the horizon, and M′ the same in the zenith, and draw MA, MC; then because any two sides of a triangle are greater than the third side, MA and AC are greater than MC or M′C; and therefore, if from each AC be subtracted, there will remain MA greater M′A.

angle under which they appear, and the idea that we form of their distance; and therefore, if by any means we associate the idea of a greater distance under the same angle, we immediately fancy the object to be greater than it really is. It is thus that a person seeing a fly hovering about a window, will sometimes take it for a bird at a much greater distance; which is a deception that almost every one has at one time or other experienced.

In the present case, however, it certainly is not the faintness of light which produces this effect, though it may tend to increase it; for the same takes place with regard to the apparent angular distance of any two stars, which is always much greater when in or near the horizon than in any other part of the heavens; and the trifling diminution which takes place with respect to their light, will not be sufficient to account for this effect.

The true cause, indeed, of this phænomenon, seems rather to arise from our being more accustomed to judge of distances in an horizontal, than in a vertical direction; and therefore, when we see the moon rising behind trees, plains, or mountains, which we know to be at a considerable distance from us; we immediately, though unconscious of the impression, refer the moon to a greater distance than when we see her more elevated, and where there is nothing interposed between us, by which our ideas of distance may be corrected.

The moon's path or orbit, as I have before observed, is inclined to the plane of the ecliptic in an angle of about five degrees and a third; and her periodical revolution round the earth is performed in twenty-seven days, seven hours, forty-three minutes, eleven seconds and a half: but in this motion there are many irregularities; so that the determination of her true place in the heavens, for any given instant of time, has ever been considered as a problem of the utmost difficulty. Newton was the first who pointed out the source of these irregularities, and the mode of investigating them; and from the principles he has laid down we have gradually obtained a more exact theory of the moon than could have been expected by former astronomers. The late lunar tables of Burg, in particular, are considered as extremely accurate; for being compared with numerous observations, as well ancient as modern, they are seldom found to differ above ten seconds from the truth.

But as the theory of the moon's motion is too intricate to admit of a popular illustration, I shall leave this subject for the present, and proceed to give you some account of the rest of the planets. Mercury, as I have already mentioned, is too near the sun to be often seen; but Venus, being higher in the system, and more easy to be observed, is found to be diversified with spots, and to have all the various phases and appearances of the moon. Mountains and valleys have also been discovered in this planet, by means of good instruments; and from the motion of her spots it is determined, that she revolves round her axis from west to east in the space of about twenty-three hours.

The face of Mars, on the contrary, is always found to be round and full, as his superior situation requires; excepting at the time of the quadratures, when a small part of the unenlightened hemisphere being turned towards us, his disc appears like the moon about three days after the full. This planet is also diversified with spots like the moon, by which his diurnal revolution is ascertained in the direction from west to east; and from his ruddy and obscure appearance, as well as from other circumstances, it is concluded that his atmosphere is nearly of the same density with that of the earth. Herschel has observed that two circles surrounding the poles of this planet, are very white and luminous, which he considers as probably owing to great quantities of snow lying there without melting.

The new planets, Vesta, Juno, Pallas, and Ceres, are by far too small to admit of such accurate observations to be made upon them as is necessary for ascertaining any particular spots, or other phænomena, which might be observed upon their discs; for as the diameter of the largest of them is supposed not to exceed four hundred miles, it can scarcely be expected that there should be spots sufficiently obvious to lead to anyconclusions relating to their rotation and figure. The same may also be observed with regard to their having satellites, which is highly probable judging from analogy with respect to their situation in the system; but these, should they really exist, must be so extremely small, as scarcely to admit of any rational expectation of their being discovered, even with the most perfect instruments.

The telescopic appearance of Jupiter affords a vast field for the curious enquirer. This planet is surrounded by several faint stripes, (Pl. XVII.) resembling belts or bands, which are parallel to the plane of his orbit, and consequently to each other. They are not regular or constant in their appearance: for sometimes only one is to be seen, and sometimes five; and, in the latter case, two of them have been known to disappear during the time of observation. When their number is most considerable, one or more dark spots are frequently formed between the belts, which increase till the whole is united into one large dusky band. This planet is also diversified with a number of large spots, which are the brightest part of his surface; but, like the belts, they are subject to various mutations, both in their figure and periods.

That remarkable spot, by the motion of which the rotation of Jupiter upon his axis was determined, first disappeared in 1694, and was not seen again till 1708, when it re-appeared exactly on the same part of his surface, and has been occasionally seen ever since. It has been conjectured that these belts are seas, and that the variations observed, both in them and the spots, are occasioned by tides, which are differently affected according to the positions of his moons. The four satellites of Jupiter were first observed by Galileo, the 7th of January 1610, soon after the invention of the telescope, but the belts were not discovered till near twenty years afterwards. (*s*)

Saturn is at too great a distance for us to distinguish, without the most powerful instrument, those varieties, which have been found upon his surface; and therefore, it is but lately that the time of his diurnal rotation has been determined; but which is now ascertained to be performed in ten hours, sixteen minutes and nineteen seconds. By means of a good telescope, we may also discover on the disc of Saturn, the faint appearance of belts, resembling those of Jupiter, and which are probably of a similar nature. The magnificent ring which is observed to encircle the body of this planet, is inclined to the plane of the ecliptic in an angle of about thirty degrees; in consequence of which its apparent figure is continually varying. When the line of its nodes

(*s*) The following Table shows the mean distances of Jupiter's four satellites, and the times of their periodic revolutions, as deduced from the most modern and accurate observations: the diameter of the planet being taken for unity.

	Proportional Distances.	Periodic revolutions in days.
1st. Satellite	5·6973	1·76913
2d.	9·0659	3·55113
3d.	14·4610	7·15455
4th.	25·4360	16·68902

points directly towards the earth, the ring, presenting its edge to the observer, becomes invisible; and if the same line points directly towards the sun, the ring cannot be seen for want of illumination. But in general its figure is that of an oval, which is broader or narrower, according as the line of the nodes is further from or nearer to the above position.

This ring has the appearance of a large flat circle, turned edgewise towards the body of the planet, without touching it; its distance from Saturn being nearly equal to its breadth, which is about thirty thousand miles. It was first discovered by Huygens, and for a considerable time was supposed to be a single undivided body. But the great improvements lately made in the construction of telescopes, have enabled astronomers to distinguish two rings at a considerable distance apart; and from several dark eccentric circles which are observed in each of them, it is supposed that they are farther decomposed, and that the whole consists of a number of rings, all in the same plane, arranged at different distances from each other.(*t*)

(*t*) The dimensions of Saturn's rings, as determined by Herschel, are as follow:

	English Miles.
Inside diameter smaller ring	146345
Outside diameter	184393
Inside diameter larger ring	190248
Outside diameter	204883
Breadth of inner ring	20000

By means of spots that have been observed on the surface of those rings, it has been discovered, that they revolve about an axis, which is perpendicular to their plane, in ten hours, sixteen minutes and nineteen seconds; being the same time in which the planet itself performs his diurnal rotation; and the same also as a satellite, at the mean distance of the ring, would perform its annual revolution, according to the second law of Kepler; which is a remarkable coincidence of the laws of gravitation, in an instance where we might least expect to find it. But simplicity and universality are the grand and distinguishing characteristics of the works of the creation.

Besides this ring, that serves as a sort of perpetual moon to enlighten the inhabitants of Saturn, he has the advantage of seven satellites, which revolve about him in the same manner as our moon revolves about the earth; and thus furnishing his dreary regions with that constant supply of light, which his remote situation, with respect to the sun, seems to render so peculiarly necessary.

The fourth satellite of Saturn was first observed by Huygens, and not long after the three first and the fifth were discovered; and these were for a long time thought to comprise the whole; but Herschel, by encreasing the powers of his teles-

	English Miles.
Breadth of outer ring	7200
Breadth of the space between the rings .	2839
Thickness of the ring	4500

copes, has discovered two others; making seven in all; the particulars of which are expressed in the note below.(*u*)

The next and highest planet in our system is Uranus; and if the immense distance of Saturn from the sun, render any observations upon him extremely difficult and uncertain, without the aid of the most powerful instruments, much more will these difficulties be increased with regard to this planet, which revolves at nearly double the distance of Saturn; and therefore, none of those varieties can be discovered on its disc which are observed in the less remote planets; consequently, nothing can with certainty be known of the duration of its diurnal motion. It has, however, been ascertained from observation, that it has six satellites revolving about it, and it is probable, judging from analogy, that it is attended by a still greater number; but which, on account of his immense distance

(*u*) Table of the proportional distances and times of the periodic revolutions of Saturn's satellites, the diameter of the planet being taken for unity.

	Proportional Distances.	Periodic revolutions in days.
1st Satellite	3080	0·94271
2d.	3952	1·37024
3d.	4893	1·88780
4th.	6268	2·73948
5th.	8754	4·51749
6th.	20295	15·94530
7th.	59154	79·32960

from us, are beyond the reach of telescopic observation.(x)

(x) The proportional distances, and the times of the periodic revolutions of the six satellites of Uranus, are as follows: the diameter of the planet being assumed as unity.

	Proportional Distances.	Periodic revolutions in days.
1st. Satellite	13·120	5·8926
2d.	17·022	8·7068
3d.	19·845	10·9611
4th.	22·752	13·4559
5th.	45·507	38·0750
6th.	91·008	107·6044

LETTER XXII.

ON COMETS, AEROLITHS, AND METEORS.

Having in my last letter explained to you the most interesting particulars relating to the planets, I shall now proceed to give you some account of the comets, those erratic bodies, which the ancients considered as enormous meteors, formed in the atmosphere, and sent as harbingers of divine vengeance. This was the prevailing opinion as early as the time of Homer, who speaks of

. . . . "The red comet, by Saturnia sent,
To fright the nations with a dire portent;
A fatal sign to armies on the plain,
Or trembling sailors on the wat'ry main."

And a similar allusion is also given by Milton, who compares the indignation of Satan, at being opposed in his passage by Death, to the burning of a comet,

"That fires the length of Ophiuchus huge
In th' arctic sky, and from his horrid hair
Shakes pestilence and war."

Tycho Brahe, and Dominique Cassini, were the first among the modern astronomers who gave these bodies a place in our system; but they appear to have been unacquainted, both with their motion round the sun, and the true figure of their orbits. These particulars were left for the determination of Newton, who has discovered the paths they describe, and the laws to which they are subject. Their revolutions are now known to be performed in very long ellipses, whose lower focus is in or near the sun, being governed throughout by the same law, of describing equal areas in equal times, which is known to regulate the motions of all the other bodies in the system.

By observations of parallax it is also found, that at their first appearance they are nearer to us than Jupiter; from which it is concluded that they are, in general, less than that planet; for if they were as large, they would be seen as far off. In their motions round the sun they are also subject to the same irregularities as the planets; but as their orbits are extremely eccentric, those variations are much more considerable. When they are near the sun, their motion is very rapid, and in the more distant parts of their orbits extremely slow; so that their vicissitudes, in this respect, are as much in the extreme as what they undergo from heat and cold.

When a comet arrives within a certain distance of the sun, it emits a fume or vapour called its tail; which shows that these bodies contain a portion of matter considerably more rare and volatile than any on the earth; for the tail begins to appear when they are yet in a higher, and consequently a colder region, than Mars. In every situation of the comet the tail is always directed to that part of the heavens which is nearly opposite to the sun; and is always greater after the comet has passed its perihelion, than during its approach towards it, being greatest of all when it has just left that point.

The head of the comet is also surrounded with a substance similar to the tail, which is called the coma; the head itself being easily distinguished from it by its shining with a much greater lustre; and the nucleus, which is the body of the comet, is still brighter than the head, but very small, and not distinguishable except by means of the best telescopes.

That part of a comet's orbit, which comes under our inspection, is so small in proportion to the whole, that it differs but little from a parabola; for which reason the dimensions of their orbits and periodical times cannot be ascertained, with any degree of precision, from a single observation. But from the re-appearance of several comets, after long intervals of time, in the same region of the heavens; and from their being found to move in the same curve, it is evident that their revolutions must be performed in certain stated times, like those of the planets. This indeed has been shown by Halley, who, from the theory of Newton, has calculated tables for determining the orbits of the comets, which, in some instances, have been found agreeable to observation.

But it is very difficult to determine with accuracy the elements of their orbits, which are so extremely eccentric, that a very small error in the observation, will change the computed orbit into a parabola or hyperbola. And as the thickness and inequality of the atmosphere, with which the comet is surrounded, render it impossible to ascertain, with any degree of precision, when either the limb, or centre, pass the wire of the telescope at the time of observation, much uncertainty must necessarily attend the result thus deduced. The only safe method therefore to determine the periods of comets, is to compare the elements of all those that have been computed, and where any remarkable coincidence is perceived, an identity may be inferred; it being extremely improbable, that two different comets should have the same inclination, the same perihelion distance, and the places of the perihelion and the node the same. By this means, the periodic time being determined, the major axis of the orbit becomes known from the laws of Kepler, and the perihelion distance being likewise obtained from observation, will also give the minor axis of the orbit.

It was thus that Dr. Halley was enabled to foretell the return of the comet in 1759; he having, by comparison, found that it had before appeared in the years 1456, 1531, 1607 and 1682, and therefore, that its period was about 75 years. But as the comets sometimes pass very near the planetary bodies of our system, a considerable variation may frequently happen in their periods of revolution, as was the case with the comet above-mentioned; and therefore, if the elements of their orbits agree in other respects, a little variation in the time of their re-appearances will be no reason for supposing them not to be the same. The two comets which appeared in 1532, and 1661, were also supposed by Dr. Halley, to be one and the same; from which he inferred that it would appear again in 1789, or 1790; but although three comets were observed in the latter year, no one of them answered, in any respect, to that whose return was expected. That remarkable comet which appeared in 1680, was also supposed to be the same which is recorded as having been seen in 1106, and that its period is five hundred and seventy-five years; but this is very doubtful, and little insisted upon by modern astronomers.

The immense distances to which these bodies are carried, and the comparatively small part of their orbit which comes under our inspection, as well as their imperfect undefined appearance in the telescope, and the great interval of time which elapses between their re-appearances, are impediments which nothing but time and the most accurate and diligent observations can remove; and therefore many ages must necessarily elapse, before the theory of comets can be brought to perfection. Every thing however, that ingenuity and industry can accomplish, may be expected from the astronomers of the present day, whose diligence and accuracy have led them to many interesting discoveries, and to whose future perseverance we may confidently look for others equally important.

The comet which appeared in September 1807, was the most conspicuous of any that had lately visited our system, and created a very lively interest and general curiosity. Numerous observations were made upon it both by the English and continental astronomers, some with a view of determining the elements of its orbit, while others were intended to ascertain its physical conformation. Those of Dr. Herschel were particularly directed to the latter object, and were continued by him from October 4th, 1807, to February 21st, 1808. From these it appears, that the nucleus of this comet was round, bright, and well defined, shining in all its parts with equal lustre, whereas, by calculating its phases it ought, had it shone only by the borrowed rays of the sun, as is generally supposed, have had a defalcation of light, proportionate to that of the moon about a day or two after the third quarter. From this it is inferred, first, that the comets shine by their own native light, and not by means of the reflected rays of the sun; and secondly, that the nucleus has a real disc, and that it is composed of a dense and solid matter similar to the planetary bodies. The nucleus itself of this comet, appeared of nearly the same magnitude as the third satellite of Jupiter; whence, by estimating its distance and other particulars, its diameter is computed to be about five hundred and thirty-eight English miles. It passed its perihelion September 13th, 1807; at which time its distance from the sun was about sixty-one millions of miles. Its motion in its orbit was direct; and its periodic revolution, according to the computation of M. Bessel, the coadjutor of Schroeter, is completed in no less than one thousand nine hundred years; but some doubt seems to be entertained of the accuracy of this result.

Various hypotheses have been advanced to account for the tails of comets; but as they are entirely speculative, it would be both unprofitable and uninteresting to enter, in this place, upon that topic. I shall, therefore, confine my remarks to that part of the subject which is of a less doubtful nature; being deduced from actual observation. First, it may be observed, that the shadow of a comet is generally projected upon its tail, so as to be distinctly visible with a good telescope. Hevelius particularly found this to be the case with respect to the comet of 1665; for in the middle of its length there appeared a dark line. The same appearance was also observed with respect to the comets of 1680 and 1744; and the same may also be distinctly seen in the comet which is visible at this time 1811.

The lengths of the tails of comets are various, and depend upon a number of different circumstances. Longomontanus mentions a comet that, in December 1618, had a tail which appeared under an angle of one hundred and four degrees; that of 1744, had also a tail which at one time subtended an angle of sixteen degrees from its body, and which was estimated to have been more than twenty-three millions of miles in length. The diameter of the nucleus of this comet was nearly equal to that of Jupiter, and formed one of the most beautiful celestial objects ever recorded. The tail of the comet of 1759 appeared under an angle of ninety degrees; and that of 1680 had its tail, according to Newton, very brilliant, and subtending an angle of seventy degrees.

This comet approached, at its perihelion, to within about five hundred and seventy-two thousand miles of the sun, and in November was not more than a semi-diameter of the earth's distance from our orbit; and consequently, had the earth at that time been near the same place, a great change must necessarily have taken place, both with regard to the inclination, and other elements of her orbit, if a total annihilation had not ensued from so near an appulse. The heat of this body, at the time of its perihelion, was estimated by Newton to have been about two thousand times hotter than red-hot iron; which is so intense, that had it been composed of matter like our earth, vapours, exhalations, and every volatile matter must have been immediately consumed and dissipated.

The number of comets belonging to our system is unknown; but from the accounts of the ancients, and the more accurate observations of the moderns, it is ascertained, that about five hundred have been seen, since the commencement of our æra; although of this number, it is probable that some of them may have re-appeared several times: however, when the attention of astronomers was called to this object, by the expectation of the return of the comet of 1759, no less than seven were observed in the course of as many years; and from 1780 to 1800, about thirty comets have been seen, and the elements of their orbits computed. From these circumstances therefore, and the probability that most of the comets of small apparent magnitudes were overlooked by the ancients, it is reasonable to conclude, that their number is considerably beyond any estimation that can be made from the observations we now possess.

But the number of comets whose orbits are settled with sufficient accuracy for us to ascertain their identity when they appear again, is about one hundred. The orbits of most of these are inclined to the plane of the ecliptic in large angles, and in their perihelions many of them come much nearer the sun than the earth does. Their motions in the heavens are also various, or different from those of the planets; some moving in consequentia, or according to the order of the signs, and others in antecedentia, or a contrary direction; but from a comparison of the whole it has been found, that the number whose motions are retrograde is nearly equal to the number whose motions are direct.(*y*)

These different motions of the comets, and the various inclinations of their orbits to the plane of

(*y*) The following Table shows the times of the last twenty-the ecliptic, could never have been the work of chance, but must have arisen from wisdom and design. For had their orbits been nearly coincident with that of the earth, the two bodies might have arrived at the point of intersection at nearly the same time, and by their shock have occasioned the most fatal consequences to our globe. But of all the comets which have hitherto been observed, there are none that are in the least likely to give any disturbance to the earth. Should any of them approach so near us as to be more attracted by

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one comets that have been observed, passing their perihelion, and their nearest approach to the sun.

Years.	Passages through the Perihelion.	Perihelion, or nearest distance from the Sun, in English miles.	Direction of their motion.
1790	Jan. 15	71 millions	Retrograde
1790	Jan. 28	101	Direct
1790	May 21	75	R
1792	Jan. 13	122	R
1792	Dec. 27	91	R
1793	Nov. 4	38	R
1793	Nov 18	142	D
1795	Dec. 15	23	D
1796	April 2	149	R
1797	July 9	50	R
1798	April 4	46	D
1798	Dec. 31	73	R
1799	Sep. 7	79	R
1799	Dec. 25	25	R
1801	Aug. 8	22	R
1802	Sep. 9	103	D
1804	Feb. 13	101	D
1805	Nov. 18	35	D
1805	Dec. 31	84	D
1806	Dec. 28	102	R
1807	Sep. 18	61	D

the earth than the sun, we might indeed, by that means, acquire another moon, which would be a change to our advantage, rather than a subject of terror and dismay.

Halley attempted to show, that the celebrated comet of 1680 was the same with that which was seen about forty-six years before Christ, or soon after the death of Julius Cæsar; and after having discovered its period to be about five hundred and seventy-five years, he concluded that this comet must also have appeared near the time of the universal deluge, and that it was probably the occasion of that catastrophe. This he imagined was effected by the immense quantity of humid vapours which composed its tail: and Whiston, who supported this conjecture with much ingenuity, was likewise of opinion, that the general conflagration will be occasioned by our being involved in the tail of the same comet, after it has been prodigiously heated in its passage from the sun.

Newton, on the contrary, conjectured, that this, as well as all the other comets, coming nearer and nearer to the sun in every revolution, would at length fall into that luminary, and serve as aliment, or fuel, to supply the loss of matter, which must arise from the continual emission of the particles of light. These, however, are mere hypotheses, and, as such, but of little value. The same also may be said of every thing that can be advanced concerning their being inhabited worlds: for if animals can exist there, they must be creatures very different from any that we have the least conception of. Some, who have indulged themselves in visionary ideas of this kind, have imagined, from the prodigious vicissitudes of heat and cold which they are subject to in different parts of their orbits, that they are the receptacles of reprobated spirits; and others, with equal propriety, place the infernal dominions in the sun.

It must be observed, however, that the conjectures concerning planetary worlds are not so exceptionable as those relating to the comets. For as the earth is shown to be a planet similar to the others in our system, we may reasonably conclude by analogy, that they must be designed for the same purposes, though, from their different proportions of heat and cold, it is not credible that beings of our make and temperament could live upon them. This, however, can scarcely be affirmed of all the planets; for the warmest climate on Mars, is not colder than many parts of Norway or Lapland, in the spring; though Jupiter and Saturn, it must be confessed, are much more so than any of the inhabited parts of our globe.

It also appears, that the greatest heat on the planet Venus, exceeds the heat in the island of Borneo, or Sumatra, in the East-Indies, about as much as the heat in those places exceeds that of the Orkney islands, on the northern coast of Scotland; so that at sixty degrees of north latitude, on this planet, if its axis were perpendicular to the plane of its orbit, the heat would not exceed the greatest heat of our earth; and of course, vegetation might be carried on, and animals, of a species like ours, might subsist. And, if Mercury's axis be supposed to have a like position, a circle round each of his poles, of about twenty degrees in diameter, would have the same temperature as the warmer regions of the earth; though in the hottest climate of this planet water would continually boil, and most inflammatory substances be dissipated and destroyed.

These estimations, however, are made upon a supposition of light and heat being reciprocally as the squares of the distances from the sun; but this seems to be by no means conclusive. For it is a fact now well established, by the aerial voyages that have been effected by means of balloons, as also from the perpetual cold on the tops of the highest mountains, that both light and heat depend upon the refractive powers of the atmosphere; being greater or less in proportion to its density or rarity. And consequently, if our earth was surrounded by an atmosphere, the rarity of which at the surface, was the same as it is now at an altitude of four or five miles, our present vegatation could be no longer carried on, and almost all animal life would become extinct. And on the contrary, if it were more dense than it is, the same effects would follow, but from an opposite cause, as the heat in the latter case would be as insupportable, as the cold in the former. It is therefore only necessary, that the planets should have atmospheres fitted to their various situations, in order to produce an equal degree of light and heat in every planet throughout the solar system.

It is not, however, at all necessary that the planets should be inhabited by animals like those upon the earth. That endless variety which we observe in every part of the creation which comes under our inspection, plainly indicates that there may be beings of whose nature and properties we can have no conception. We cannot suppose that the creative powers of the Deity have been employed only in peopling our little globe, which is but an atom in the universe: it is most probable, that there is an order of existences, in every planet, peculiar to its end and design, and that the Creator has adapted the inhabitants of each to their situation. Whether we shall ever be permitted to see the grand scheme of nature completely unfolded, is a matter beyond the reach of science to determine; but we have the highest reason to expect that our prospects will be further extended, and that our hopes of contemplating the more glorious works of creation will not be disappointed.

I have thus given you a popular view of the three distinct orders of bodies which compose the solar system; but besides the planets, satellites, and comets, which may be considered as permanent and regular, there are other bodies of a very singular nature, which it is even doubtful whether or not they may be properly considered as subjects of astronomical investigation; as, however, they are attended with phænomena of a very novel and and curious description, a short account of them cannot fail of proving both interesting and instructive.

The bodies to which I allude are called aerolиths, or air stones, having received this denomination from the circumstance of their falling from, or through our atmosphere, and frequently penetrating a considerable depth into the earth; being commonly preceded by a luminous appearance which indicates their motion in the heavens.

Meteors, or fire-balls, have, in all ages and climates, been observed, at times, to traverse the higher regions of the air; and many of them have been described by eye-witnesses. A remarkable phenomenon of this kind was observed in 1783, when a meteor exceedingly large and brilliant passed over England and a considerable portion of the continent of Europe, illuminating every place over which it passed with an awful grandeur that astonished every beholder; its motion was amazingly rapid; and from observations made upon it in different places, it is computed that its diameter was little less than three quarters of a mile, and its altitude above the terrestrial surface, at least sixty miles.

The motion of meteors in general is accompanied with a hissing noise, resembling that of a shell in the air when projected from a piece of ordnance; and at their disappearance an explosion takes place resembling that of a clap of thunder; which is usually attended by the fall of several stones of different magnitudes, that bury themselves in the earth; many of them continuing luminous till they reach the surface; being then still warm, and bearing evident marks of recentfusion. These stones are frequently mentioned by ancient authors, but the truth of their reports was much doubted, and supposed to have had no other foundation than in the chimerical ideas of fanciful philosophers. But since, of late years, the truth of the fact has been positively ascertained, considerable attention has been paid to this curious subject; many recent falls of a similar kind have been well attested; and the bodies themselves submitted to a chemical analysis. From this latter process one of the strongest characteristics of aeroliths has been deduced; which is, that they bear an exact resemblance to each other, at the same time that they are totally different from any known terrestrial body.

I shall not, of course, enter here into a minute description of their component parts, as that subject belongs properly to chemistry; but shall barely observe, that they are composed of a mixture of earths and metals, in certain proportions, which have been found to obtain in all those that have hitherto been examined, on whatever part of the globe they may have fallen; their specific gravity being also nearly the same. This striking resemblance in their composition seems to indicate that they have a common origin; while their dissimilarity to all terrestrial substances, denotes it to be foreign to our globe; but what it is, or the cause to which it may be attributed, has, at present, eluded the researches of every philosophical enquiry which has been instituted, in order to elucidate this interesting question. But though no physical explanation of the origin or formation of these bodies has been yet found, various hypotheses have been advanced on one hand, and refuted on the other. Some have attributed them to terrestrial volcanoes, and others to those of the moon; and on submitting the latter supposition to computation, it has been ascertained, that a velocity of about four times that commonly given to a cannon ball, would be sufficient to bring them within the sphere of the earth's attraction; after which they would fall towards its centre from the established laws of gravity. And as the existence of such volcanoes has been discovered from observations on the lunar disc, and those of the earth being known to possess a much greater power than is required in the present case, this hypothesis is not so extravagant as it may on the first view of it be imagined.

Other philosophers have supposed them to be small planets, which coming within the attractive power of the earth, are drawn towards it, and take fire from the resistance and friction which they experience in passing through our atmosphere; to which hypothesis, the discovery of the planets Ceres, Juno, &c. is considered by some, as giving a considerable degree of probability. But the most general opinion of modern chemists is, that they are concretions, formed in the atmosphere itself; although at present we are without the support of sufficient experiments to countenance this supposition. Various objections, indeed, might be made against every hypothesis that has yet been advanced, to account for the origin of these singular substances; which are found of different magnitudes, weighing from two or three pounds, to several hundred weight. All that is known with certainty on the subject is, that they are the fragments of meteors, or fire-balls, that have exploded in the atmosphere; but whence they derive their origin, and to what cause it may be attributed, are questions which at present are involved in the greatest mystery, and will probably continue for ages to baffle all the attempts of philosophers to explain them.(*z*)

(*z*) The following are some of the most interesting and best authenticated facts, that have been hitherto related, respecting the falls of aeroliths.

Substances.	Places where they fell.	Period of their fall.	Testimony.
About 1200 stones, one of 120lbs. and another of 60lbs.	Padua, in Italy.	1510	Cardan.
A shower of viscid matter.	Ireland.	1695	Muschenbroeck.
A stony mass.	Niort, Normandy.	1750	Lalande.
Twelve stones.	Sienna, Tuscany.	July 1794	Earl of Bristol.
A stone of 51lbs.	Wold Cottage, Yorkshire.	Dec. 13, 1795.	Captain Topham.
Shower of stones.	Benares.	Dec. 19, 1798.	J. L. Williams, Esq.
Mass of 70 cubic feet.	America.	April 5, 1800.	Philosophical Magazine.
Several stones from 10 to 17lbs.	Normandy.	April 26, 1803.	Fourcroy.
Mass of iron, 14 quint.	Siberia.	Very old.	Pallas, Chladne, &c.

LETTER XXIII.

OF THE ECLIPSES OF THE SUN AND MOON.

Of all the phænomena of the heavens, there are none that engage the attention of mankind more than eclipses of the sun and moon; and to those who are unacquainted with astronomical principles, nothing appears more extraordinary than the accuracy with which they can be predicted. In the early ages of antiquity, ere religion and science had enlightened the world, appearances of this kind were generally regarded as alarming deviations from the established laws of nature, and but few, even among philosophers themselves, were able to account for them. At length, when men began to apply themselves to observations, and the celestial motions were better understood, these phænomena were found to depend upon a regular cause, and to admit of a natural and easy solution.

It is to be observed, however, that most of the ancient calculations of eclipses must have been extremely defective; for as astronomy, in those times, was but imperfectly understood, all its dependent parts must have been subject to great inaccuracies. It is only since Newton has unfolded the theory of gravitation; and the science of mechanics has been brought in to give its assistance to philosophy, that we have had a just idea of the construction of the universe; and though eclipses might have been computed independently of this knowledge, yet the calculations must have been far less exact than they are at present.

The accounts which are to be found in many of the early historians, concerning the prediction of eclipses, by Thales, Anaxagoras, and others, who lived long before the commencement of the Christian æra, are only to be understood of some of the most remarkable of these phænomena, which a gross calculation might determine, sufficiently near the truth to excite the admiration of an uninformed age. There are many elements that are used in the exact computation of solar eclipses in particular, which astronomers, in a less advanced state of the science, must have been totally unacquainted with; and as the moderns, by these means, have rendered their calculations far more accurate and precise, it affords a convincing proof, even to the most illiterate, that the principles from which such a perfect knowledge of the heavenly motions is derived, must be just and undeniable.

To enter into a popular explanation of all the principles of this doctrine, would be no easy task. I shall therefore only attempt to give you a general idea of the subject, and to show you, without the embarrassment of calculations, the foundation upon which it depends. In the first place, then, it is to be observed, that all opaque or dark bodies, when they are exposed to the light of the sun, cast a shadow behind them in an opposite direction: and as the earth is a body of this kind, whose shadow extends over a large space, and to a great distance, it is plain that the moon, in passing through this space, must be deprived of her light, or suffer an eclipse.

And because the earth is spherical, the figure of the shadow would be cylindrical, if the earth and sun were of equal magnitudes: but if the earth were larger than the sun, the figure of the shadow would be that of an inverted cone, growing thicker and thicker the farther it extended; so that in both these cases it would run out into infinite space, without ever terminating or coming to an end, and eclipse the superior planets Mars, Jupiter, and Saturn, when they were in opposition to the sun. But as this never happens, it is plain that the sun is larger than the earth; and that the earth's shadow must be conical, and end in a point.

The figure of the moon's shadow is also that of a cone; and when it falls upon any part of the earth, the inhabitants of that part will be involved in darkness, and the sun will seem to them to be eclipsed as long as the shadow covers them. But as the moon is much less than the earth, and its shadow can extend over but a small portion of the earth's surface, there will be total darkness only in that space where the shadow falls; and in the circumjacent places, the inhabitants will see a greater or less part of the sun's disc obscured, according as they are nearer to or farther from the shadow: so that eclipses of the sun are always confined to particular places; but those of the moon may be observed from every part of the earth, when she is above the horizon at the time the eclipse happens.

If the sun were no larger than the moon, the moon's shadow would frequently extend over a portion of the earth's surface of more than two thousand miles broad; but this never happens: for, except in total eclipses of the sun, when the shadow falls very obliquely, it is seldom found to be one hundred and fifty miles in breadth: so that from this circumstance, as well as from many others, it is sufficiently evident that the moon must be much less than the sun. And since it is likewise found, from the time of the duration of many lunar eclipses, that the earth's shadow is large enough to cover the moon, if her diameter were three times greater than it is, it also follows that the earth must be larger than the moon.

From what has been said, it is plain that there can be no lunar eclipse but at the time of full moon, or when she is opposite to the sun; and that an eclipse of the sun can never happen but at the time of a new moon, or when she is in conjunction with that luminary: for it is only at those times that the earth and moon are in a straight line with the sun, or that the shadow of the one can fall upon the other. And since there is a new and full moon every month, it may be naturally enough imagined that there should be two eclipses in a month, one of the sun, and the other of the moon: but this is far from being the case; for there are but few eclipses in comparison to the number of new and full moons.

If, indeed, the plane of the moon's orbit were coincident with that of the earth's, the moon would then pass through the middle of the earth's shadow, and be eclipsed at every full: and, in like manner, the moon's shadow, falling upon some part of the earth, would occasion an eclipse of the sun at every change. But one half of the moon's orbit being elevated about five degrees and a third above the plane of the ecliptic, and the other half as much depressed below it, the moon can never be in the same plane with the earth, but when she is in the nodes, or one of the two points where the orbits intersect each other. And, therefore, as the moon may make a number of revolutions round the earth, before a new or full moon takes place in one of those points, it is plain that there may be no eclipse, either of the sun or moon, in the space of several months.

When the nodes, or two points of intersection, are in a right line with the centre of the sun, at the time of a new moon, the moon's shadow will fall upon the earth, and occasion a solar eclipse; and if they have the same situation at the time of a full moon, the earth's shadow will fall upon the moon, and occasion a lunar eclipse. But when the sun and moon are more than seventeen degrees from either of the nodes at the time of conjunction, the moon is then generally too high or too low in her orbit for any part of her shadow to fall upon the earth. And when the sun is more than twelve degrees from either of the nodes, at the time of opposition, the moon is commonly too high or too low in her orbit to go through any part of the earth's shadow; so that in both these cases there will be no eclipse.

But when the moon is less than seventeen degrees from either of the nodes at the time of conjunction, a greater or less portion of her shadow will fall upon the earth, as she is more or less within this limit: and when she is less than twelve degrees from the node, at the time of opposition, she will go through a greater or less portion of the earth's shadow, according to her situation. And as the sun commonly passes by the nodes but twice a year, and the moon's orbit contains three hundred and sixty degrees, of which seventeen, the limit of solar eclipses, on either side of those points, and twelve the limit of lunar eclipses, are but small portions, it is easy to perceive that there must be many new and full moons without any eclipses.

The limits I have mentioned are subject to some variations; but, as a scrupulous accuracy, in a popular explanation of this kind, would be tedious and unnecessary, I shall proceed to illustrate the general doctrine by a figure. For this purpose, let A B C D (Pl. XIX.) be the ecliptic, or the earth's path in the heavens; R S T U a circle lying in the same plane, and V W X Y the moon's orbit; one half of which X Y V is above the ecliptic, and the other half V W X below it. Then will the points V and X, where the two circles intersect each other, be the moon's nodes; and the right line X E V, drawn from the one to the other, through the earth's centre, will be the line of the nodes; which is carried in a position, nearly parallel to itself, round the sun in a year.

Now it is plain from the figure, that if the moon moved round the earth in the circle R S T U, which is coincident with the plane of the ecliptic, her shadow would fall upon the earth every time she was in conjunction with the sun; and at every opposition she would go through the earth's shadow: so that in this case the sun would be eclipsed at every change, and the moon at every full. But as the moon moves in the circle V W X Y, which is inclined to the former in an angle of about five degrees and a third, there can be no eclipse but when she is in or near one of the nodes V or X, at the time of full or change: for in all other positions, she will be too much out of the plane of the ecliptic for her shadow to fall upon the earth, or for the earth's shadow to fall upon her.

When the moon is in conjunction with the sun at *i*, her shadow N must fall upon the earth at *a*, because she is then very near one of her nodes; and at her opposition *n*, she must go through the earth's shadow I, because she is then near the other node. But in the time she goes once round the earth, according to the order of the letters X Y V W, the earth will have advanced forwards from E to *e;* and as the line of the nodes V E X, is always carried nearly parallel to itself, the moon at her next change will be at the point *f*, which is too high above the ecliptic for any part of her shadow to fall upon the earth. And, for the same reason, as the earth is still moving forward in its orbit, the moon, at her next opposition, will be at *g*; which is too far below the ecliptic for her to go through any part of the earth's shadow.

Again, when the earth has moved through a quarter of the ecliptic to F, and the moon is in conjunction with the sun S, she will not be at *k*, in a plane coincident with the ecliptic, but above it at Y, in the highest part of her orbit: and, in this situation, the point *b* of her shadow O, will fall as far above the earth as possible. For the same reason, the moon, at her next opposition, will not be at *o*, but at W, in the lowest part of her orbit, in which situation she will be as far below the earth's shadow as possible: so that in both these cases the line of the nodes V E X will be about ninety degrees from the sun, and the two luminaries will be as far removed from the limits of eclipses as the nature of their orbits will admit.

When the earth has gone half round the ecliptic, from E to G, the line of the nodes V G X, is nearly directed towards the sun at S, and then the new moon *l* casts her shadow P upon the earth G; and the full moon *p* goes through the earth's shadow L, which brings on eclipses again, as when the earth was at E. And when the earth has gone three quarters round the ecliptic to H, the new and full moons fall not at *m* and *q*, in a plane coincident with the ecliptic, but at W and Y, about five degrees and a third below and above it: so that, in this case, the moon's shadow falls as far below the earth, and the earth's shadow as far below the moon, as possible; and they are now removed at as great a distance from the limits of eclipses as when the earth was at F.

The point X, where the moon's orbit crosses the ecliptic, is called the Ascending Node, because the moon ascends from it above the ecliptic; and the opposite point of intersection V, is called the Descending Node, because the moon descends from it below the ecliptic. And when the moon is in the higher part of her orbit X Y V, she is said to have north latitude; and when she is in the lower part V W Y, she is said to have south latitude. It appears, also, from what has been already observed, that when the earth is at E and G, the moon is about her nodes at new and full, and in her greatest north and south latitude at her quarters: but when the earth is at F or H, the moon is in her greatest north and south latitude at new and full, and in the nodes about her quarters.

If the line of the nodes were always carried parallel to itself round the sun, there would be just half a year between the conjunctions of the sun and nodes. But as the nodes shift backwards, or contrary to the earth's annual motion, about nineteen degrees and one third in a year, the same node will come round to the sun about nineteen days sooner every year than upon the preceding one; so that from the time when the ascending node X passes by the sun, as seen from the earth at E, there will be only one hundred and seventy-three days before the descending node passes by him. And, consequently, at whatever time of the year we have eclipses about either of the nodes, we may expect, in about one hundred and seventy three days afterwards, to have eclipses about the other node.

And when, at any time of the year, the line of the nodes is in the situation V G X, at the same time next year it will be in the situation *r* G *s*; the ascending node X having gone backwards, or contrary to the order of the signs, from X to *s*, and the descending node from V to *r*, each about nineteen degrees and a third. At this rate, therefore, the nodes will shift through all the signs and degrees of the ecliptic in eighteen years and two hundred and twenty-five days; and in this time there would always be a regular period of eclipses, if any complete number of lunations were finished without a fraction. But this never happens; for if both the sun and moon should set out together from a line of conjunction with either of the nodes, in any point of the ecliptic, the sun would go through eighteen annual revolutions and two hundred and twenty-two degrees over, and the moon through two hundred and thirty lunations and eighty-five degrees of the two hundred and thirty-first, by the time the nodes came round to the same point of the ecliptic again; and, therefore, the sun would be then one hundred and thirty-eight degrees from the node, and the moon eighty-five degrees from the sun.

After the sun, moon, and nodes, however, have been once in a line of conjunction, they will return so nearly to the same state again in two hundred and twenty-three mean lunations, or about eighteen years and ten days, as that the same node, which was in conjunction with the sun and moon at the beginning of the first of these lunations, will be within less than half a degree of a line of conjunction with the sun and moon again, when the last of these lunations is completed. And, therefore, in that time, there will be a regular period of eclipses, or returns of the same eclipses for many ages. But the falling back of the line of conjunction of the sun and moon, with respect to the line of the nodes, in every period, will at length exhaust it, and after that it will not return again in less than twelve thousand four hundred and ninety-two years.

Another period for comparing and examining eclipses, which happen after long intervals of time, is that which consists of six thousand eight hundred and ninety mean lunations, or about five hundred and fifty-seven years and twenty-one days; in which time the sun and node will meet again so nearly, as to be little more than eleven seconds distant: but it will not be the same eclipse that returns, as in the shorter period above-mentioned. These periods are said to have been discovered by the Chaldeans, six or seven hundred years before the birth of Christ; but M. Bailly, in his "Histoire de l'Astronomie Ancienne," has endeavoured to show, that the invention is of a much earlier date. He finds, from the testimonies of ancient authors, that these periods, as well as those of nineteen, and six hundred years, which serve to show the returns of the new moons, were known to the Arabs, Indians, Chinese, and Tartars, long before the sciences were cultivated in Greece. And as a knowledge of this kind could have only been obtained from a long series of observations, or a general and perfect acquaintance with the celestial motions, he thinks it probable, that these, as well as many other discoveries of equal importance, are due to the antediluvians, or the most ancient inhabitants of the earth.

But as this is a favourite hypothesis of M. Bailly's, in which I apprehend but few astronomers will agree with him, I shall leave the justification of his tenets to himself, and proceed to the illustration of our subject. In the first place, then, it will be necessary to give you some account of the different kinds of eclipses, and the causes which produce them. And here nothing more is requisite to be observed, than that every variety of this kind that can take place, either with respect to the sun or moon, is owing to the elliptical figure of their orbits, and the position they are in at the time the eclipse happens.

When the moon changes at her least distance from the earth, and is within the proper limits of the node, she will appear large enough to cover the whole solar disc; and those inhabitants of the earth where her shadow falls, will have the sun entirely hid from their sight for some minutes. But when the moon changes at her greatest distance from the earth, and is near enough to the node, her diameter will subtend a less angle than the sun's; and, on that account, her dark shadow must terminate in a point before it reaches the earth; and at the place over which it hangs, the sun's edge will appear like a luminous ring all round the body of the moon.

The former of these is called a total eclipse, and the latter an annular one. And as the moon's apparent diameter when largest, exceeds the sun's when least, by only about a minute and a half of a degree, the total darkness, in the greatest eclipse of the sun that can happen at any time and place, will continue no longer than whilst the moon goes through a minute and a half of her orbit from the sun; which she describes in a little more than three minutes of time. But when the change happens within seventeen degrees of the node, and the moon is at her mean distance from the earth, the point of her shadow will just reach the earth, and the darkness, on the small spot where it falls, can be only of a moment's continuance.

A total eclipse of the sun is a very curious spectacle. Clavius, who observed the one which happened on the 21st of August, 1560, at Coimbra, in Portugal, observes, that the obscurity was greater, or at least more striking and sensible, than that of the night. It was so dark for some time, that he could scarcely see his hand; some of the largest stars made their appearance for about a minute or two, and the birds were so terrified that they fell to the ground. These eclipses, however, happen but seldom at any particular place; and annular ones are much less common: the last remarkable one of this kind being that of the 1st of April, 1764, which was seen at Rennes, Calais, and Pello in Lapland.

Dionysius of Halicarnassus mentions two total eclipses of the sun that happened, one at the birth of Romulus, and the other at his death; in each of which the obscurity was as great as in the darkest night. But this account, like that of the prodigies which were seen at the death of Cæsar, deserves but little credit. In ancient times, every great event was said to have been accompanied with comets or other portentous appearances; and eclipses of the sun in particular were always regarded as calamitous omens, presaging the death of kings, or some illustrious character. This superstition is frequently alluded to by the poets, and is the foundation of one of the noblest similes in the Paradise Lost.

> .... "As when the sun new risen
> Looks through the horizontal misty air
> Shorn of his beams, or from behind the moon
> In dim eclipse disastrous twilight sheds
> On half the nations, and with fear of change
> Perplexes monarchs: darkened so, yet shone
> Above them all th' Arch-Angel."

In China, where astronomy is made subservient to the interest of the state, they have particular ceremonies appropriated to those days on which eclipses are to take place; and according to the accounts of the missionaries, both the prince and the people are scrupulously exact in the observance of them. The chief of the Tribunal of the Mathematics is here a grand, but dangerous appointment; for, under the reign of the emperor Chou-kang, the two principal astronomers, Ho and Hi, were condemned to death, on account of their omitting, through negligence and intoxication, to announce the precise time of an eclipse of the sun. This eclipse, which happened 2169 years before Christ, and a remarkable conjunction of four of the planets, which their annals affirm to have taken place at a still earlier period, are thought, by some astronomers who have examined the subject, to be strong proofs of the authenticity of the Chinese chronology.

But to return to our subject.—Besides the dark shadow of the moon already mentioned, there is another fainter one, called the Penumbra, which always accompanies a solar eclipse, and takes place upon those parts of the earth which are only partially deprived of the sun's rays. For let S be the sun, E the earth, and *m* the moon (Pl. XX. fig. 1.). Then if two right lines be drawn from A and B to touch the body of the moon in *r* and *s*, they will form the cone *r o s*, which is the figure of her dark shadow, as it falls upon the earth at *o*; and two other lines, drawn through the same points transversely, will show the limits of the penumbra, or faint shadow C *r s* D; in every part of which space there is more or less light, according as it is farther from, or nearer to the centre O.

And as the moon moves eastward over the sun's disc, the dark shadow describes the path C D, and all the inhabitants, living within that tract, will have the sun successively and totally eclipsed; whilst those who are at some distance from it, will have a partial eclipse, according as they are more or less within the circle of the penumbra C r s D. So that when the penumbra first touches the earth, the general eclipse begins, and when it leaves the earth the eclipse ends; the whole duration, at a mean rate, being about five hours and fifty minutes.

The earth's dark shadow, F C D G, (Pl. XX. fig. 2.), is also encompassed by a penumbra, in the same manner as the moon's, which is faint towards the edges C r and D s, and more obscure towards C F and D G; and this is the reason why it is so difficult to observe exactly either the beginning or end of a lunar eclipse, even with a good telescope; for the earth's shadow is so faint and ill-defined about the edges, that when the moon is either just touching or leaving it, the obscuration of her limb is scarcely sensible. But both the beginning and end of solar eclipses are visible instantaneously; for the moment the edge of the moon's disc touches the sun's, his roundness seems a little broken on that part; and the moment she leaves it, he appears perfectly round again.

The moon, when totally eclipsed, is seldom invisible, but generally appears of a dusky colour, resembling tarnished copper, which some have thought to be owing to her own native light; but the true cause of this appearance is the scattered beams of the sun, which are so bent into the earth's shadow, in their passage through the atmosphere, as to afford us a sufficient quantity of light to render the moon visible. There have, however, been eclipses of the moon, when in that part of her orbit nearest the earth, in which she has entirely disappeared; but these instances are very rare. Hevelius mentions one of this kind, which happened on the 25th of April, 1642, when he was not able to distinguish the place of the moon, even with a good telescope, although the sky was sufficiently clear for him to see stars of the fifth magnitude.

From what has been said, it is also plain, that there may be a total eclipse of the moon, although she be not exactly in either of the nodes at the time the eclipse happens; for as the diameter of the earth's shadow is much greater than that of the moon, it is plain that she may be wholly involved in the dark cone without passing directly through its axis. The moon may likewise be at such a distance from the node, that only a part of her body can enter the earth's shadow, and then we shall have a partial eclipse of the moon, which will be greater or less according to her situation. But when it happens that the full moon takes place exactly in one of the nodes, then the axis of the earth's shadow will pass through the centre of the moon, and it will be a total and central eclipse.

The diameters of the sun and moon are supposed to be divided into twelve equal parts, (Pl. XVIII. fig. 3.) and an eclipse is said to be of so many digits, according to the number of those parts which are involved in darkness. It must also be observed, that an eclipse of the moon always begins on her eastern side, and goes off on her western; and that an eclipse of the sun begins on his western side, and goes off on his eastern. And all that the moon is eclipsed above twelve digits, shows how far the shadow of the earth extends over her body, on that edge to which she is nearest at the middle of the eclipse.

Eclipses of the sun are more frequent that those of the moon, because his ecliptic limits are greater; and yet we have more visible eclipses of the moon than of the sun; which is owing to their being seen from all parts of the earth, where the moon is above the horizon at the time the eclipse happens; whilst those of the sun can only be observed on that small portion of the hemisphere on which the moon's shadow falls. The greatest number of eclipses, of both luminaries, which can happen in a year, is seven, and the least two; but the most usual number is four; and it is very rare that there are more than six, one half of which are generally invisible at any particular place.

These are the principal particulars relating to the doctrine of eclipses, which admit of a familiar illustration, and if they be properly considered, it will not be difficult to conceive how astronomers are able to foretel the exact time when any phænomenon of this kind will happen. For as an eclipse can only take place at the time of a new or full moon, the chief requisites are to determine the number of mean conjunctions and oppositions that will arrive in every year, and the true places of the sun and moon in their orbits at each of those times. And if from this it appears, that the two luminaries are within the proper limits of the node, there will be an eclipse, or otherwise not, agreeably to what has been already observed upon this subject.

But in order to facilitate these operations, we have astronomical tables ready computed, from the theory of gravitation, by which the places of the heavenly bodies, and every other necessary particular, may be easily found for any given instant of time. Dr. Halley has also given a catalogue of all the eclipses that took place from the year 1701 to 1718, which the author of "L'Art de verifier les Dates," and others, continued up to the year 1800; so that by means of the period of nineteen years, in which there is found to be nearly a regular return of the same eclipses, it is easy to institute a calculation, that will determine, to a great degree of precision, the times in which they will happen.

This method, however, is not strictly scientific; and there are, besides, many other elements employed in calculating the quantity and duration of eclipses, which, as you are unacquainted with the higher parts of mathematics, it is scarcely possible to explain in a clear and satisfactory manner. If what has been said should lead you to wish for a farther acquaintance with this doctrine, you will find it amply treated of by Lalande, in his Astronomy, Vince, and others; but these authors cannot be read to any advantage, till you have obtained a previous knowledge of many other branches of science.

LETTER XXIV.

OF THE NEW PLANETS, AND OTHER DISCOVERIES.

It is a general and immemorial tradition, which is countenanced both by sacred and profane history, that prodigious changes and revolutions have taken place in our globe since its first formation: and the bare inspection of the earth gives great weight to this opinion. We can perceive, in many instances, that the waters of the ocean have not always been confined within their present bounds. The vegetables and fishes of India, which are found in the petrifactions of Europe; and the number of shells, and other marine productions, discovered in ranges of mountains very remote from the sea, can be accounted for upon no other principle. This was a doctrine which was taught both by Pythagoras and his followers; and Ovid, in explaining the tenets of that sect, speaks in the name of all the Oriental philosophers, when he says,

> "The face of places, and their forms, decay;
> And what was solid earth converts to sea;
> Seas, in their turn, retreating from the shore,
> Make solid lands what ocean was before;
> And far from strands are shells of fishes found;
> And rusty anchors fixed on mountain ground:
> And what were fields before, now mark'd and worn
> By falling floods, from hills to valleys turn:
> And crumbling still descend to level lands;
> And lakes, and trembling bogs, are barren sands:
> And the parch'd desert floats in streams unknown,
> Wondering to drink of waters not her own."

To these testimonies, which seem consonant both with history and experience, may be added another still more singular; which is that of the ancient Egyptians, who maintained that the sun, in former ages, had risen in the west and set in the east. It was, indeed, a tradition as obscure as their hieroglyphics; and Herodotus, Plato, Diogenes Laertius, and Plutarch, who all mention this revolution, must be considered as authors by far too modern to deserve much credit with regard to such antiquities. They are, however, so many remaining witnesses that this opinion once prevailed; and, from the discoveries of the moderns, some have been induced to believe, that the idea, extravagant as it may seem, was not altogether without foundation.

The best modern astronomers are now generally agreed, that the angle which the ecliptic makes with the equator is continually decreasing, at the rate of about one minute in a hundred years; and therefore, if this diminution should proceed, the two circles, in about one hundred and forty thousand years, would coincide, and the sun, moving in or near the equator, would make equal days and nights all over the globe for many ages. There is reason to believe, however, that this enormous period will never be completed; and to seek for a solution of the Egyptian ænigma, as some writers have done, from these principles, is to invalidate the truth of revelation, and the most authentic records of sacred history. A revolution of this kind, sufficient to reverse the four cardinal points of the compass, could not have been accomplished in less than two millions of years; and this is giving a length of duration to the world, that but few will admit.

We are told by Diodorus Siculus, that the philosophers of Babylon, at the time of Alexander's entry into that city, reckoned four hundred and three thousand years from the beginning of their astronomical observations. And upon a supposition that the ecliptic was first perpendicular to the equator, and afterwards began to approach towards it, according to the rate above-mentioned, this period very nearly agrees with the diminution of the angle, which, in that time, had taken place, and reduced the obliquity to twenty-three degrees and a half. But from this it is not to be inferred, that the Chaldean astronomers had actually observed the celestial motions for so many ages. It is the custom of all conquered nations to boast of their origin, and to endeavour to recover by their antiquity the glory which they have lost by their weakness. They were, most probably, acquainted with the varying obliquity of the ecliptic, and having discovered this epoch by calculation, pretended that it was derived from real observations.

Some, however, are of a contrary opinion; and from the uncertainty of ancient observations, are disposed to believe, that the obliquity of the ecliptic has been always the same. But in this they are certainly mistaken; for besides the apparent decrease of this angle, which has been observed by almost every astronomer since the time of Hipparchus, the variation of latitude in the fixed stars is such as could arise from no other cause. Ptolemy tells us expressly that he determined the obliquity, for several years together, to be twenty-three degrees fifty-one minutes, and it is now known to be twenty-three degrees twenty-eight minutes, which appears to be too great a difference to be attributed to any defect in his observations. But independently of ancient testimonies, the attention which has been bestowed upon this subject for near a century past, has enabled us to decide with certainty that the diminution is real, and that it is confined withing certain limits.

Mathematicians have shown, that the variation of the angle here mentioned, is produced by the attraction of the planets; but as the principles which they have employed are too abstruse and complicated to be explained in a popular manner, I shall not attempt to illustrate them; but proceed to give you some account of another discovery, no less important than the former. Hipparchus, in comparing his observations with those of Timocharis, which had been made at Alexandria about a century before, first perceived that the stars changed their positions, and appeared to have a slow motion from west to east, with regard to the equinoctial points.

This change of the stars in longitude, which has now become sufficiently apparent, is owing to a small retrograde motion of the equinoctial points, of about fifty seconds in a year, which is occasioned by the attraction of the sun and moon upon the protuberant matter about the equator, in nearly the same manner as the action of the sun produces the retrograde motion of the nodes of the moon. The same cause also occasions a small deviation in the parallelism of the earth's axis, by which it is continually directed towards different points in the heavens, and makes a complete revolution round the axis of the ecliptic in about twenty-five thousand nine hundred and twenty years.

The former of these motions is called the precession of the equinoxes, and the latter the nutation of the earth's axis. And in consequence of this shifting of the equinoctial points, an alteration has taken place in the signs of the ecliptic; those stars, which in the infancy of astronomy were in Aries, being now got into Taurus; those of Taurus into Gemini, &c. So that the stars which rose and set at any particular season of the year, in the times of Hesiod, Eudoxus, Virgil, &c. will not at present answer to the descriptions given of them by those writers.

"Some say the zodiac constellations
Have long since chang'd their antique stations
Above a sign, and prove the same
In Taurus now, once in the Ram.
Affirm the Trigons chop'd and chang'd
The watr'y with the fiery rang'd:
That in twelve hundred years and odd,
The sun has left his ancient road,
And nearer to the earth is come
'Bove fifty thousand miles from home."

HUDIBRAS.

It was by means of this retrogressive motion of the equinoctial points, that Sir Isaac Newton was enabled to fix the time of one of the most remarkable epochs of chronological history, and to throw some light upon the fables of antiquity. He proves, from the testimonies of several ancient authors, that Chiron the Centaur, who was one of the Argonauts, constructed a sphere, on which the Colure of the Equinoxes was made to pass by certain stars, and to cut the ecliptic in the middle of the signs Aries and Libra. And by finding what stars the same circle passed by in the year 1689, when he first made this enquiry, and in what points it cut the ecliptic, the difference, allowing a change of one degree in about seventy-two years, gave him the Æra of the Argonautic Expedition; and thence, by a necessary consequence, that of the Trojan war: upon which two great events all the ancient Chronology entirely depends.

But of all the discoveries in this science, none will be thought more singular than that which has has lately been made by Herschel, who, as he was pursuing a design which he had formed of observing, with telescopes of his own construction, every part of the heavens, discovered in the neighbourhood of H Geminorum, a star, which, in magnitude and situation, differed considerably from any that he had before observed, or found described in the catalogues.

This induced him to consider it with particular attention, and by continuing his observations, he found that it could not belong to any class of new or temporary stars which had been seen at particular times by preceding astronomers: for by measuring its motion by a micrometer, he found it to move regularly, according to the order of the signs; that its apparent diameter was on the increase, and that it declined but little from the ecliptic; which circumstances at first led him to conclude, that it must be some comet belonging to our system, whose remote situation had hitherto prevented it from being observed.

As a comet, however, it seemed particularly singular, since no tail, or any hairy or nebulous appearance, could be perceived, by which those bodies are always distinguished from the rest of the system; on the contrary, it was found to shine with a faint steady light, something paler and more faint than Jupiter, and appeared about four seconds in diameter. Its differing so materially from other comets was ascribed to its immense distance from the sun, at which the heat was not sufficient to rarify the gross atmosphere, so as to extend it far enough from the body of the comet for it to become visible.

A discovery of this nature soon engaged the attention of the most eminent astronomers of Europe, and many observations were accordingly made at different times and places. Amongst which, those of M. Lexell, of Petersbourg, appear to have been of particular service, in determining the real nature and class of celestial bodies to which this phænomenon belongs. These observations, compared with those of other eminent astronomers, sufficiently prove, that this star is a PRIMARY PLANET, belonging to the solar system, which, till the 13th of March 1781, when it was first seen by Herschel, had escaped the observation of every other astronomer, both ancient and modern.

From a series of observations, continued for eight months, during which time this planet was both in opposition and conjunction, and had moved through a part of its orbit of more than six degrees, Lalande calculated its course for 1782, and found that its distance from the sun is near nineteen times greater than that of the earth; that its magnitude is about eighty-nine times greater than than the earth's; and that it revolves round the sun in an orbit, which is nearly circular, in about eighty-two years.

The apparent diameter of this planet being but about four seconds, it can seldom be seen very plainly by the naked eye, but may easily be discovered in a clear night, when above the horizon, by a good telescope; its situation, with respect to the fixed stars, being previously known. Whether it was attended by any satellites was, at first, only a matter of conjecture; but Herschel has since discovered six; and, from the remote situation of the planet, there is reason to believe that there may be others, which have not yet been observed. He has also ascertained their periodical times with great accuracy; the particulars of which have been before given.

As a mark of respect to his present Majesty, and to convey an idea to posterity of the time and place of the discovery, Herschel has distinguished this planet by the name of the Georgium Sidus, following the example of Galileo, who, in honour of his patrons, the illustrious House of Medici, called the Satellites of Jupiter, which he first discovered, the Medicean Stars. But foreign astronomers, preferring a similar denomination for all the planets, have given it the name of Uranus, by which this planet is now generally distinguished.

This discovery, which at first appears more curious than useful, may yet be of great service to astronomy; the circumstance of a primary planet having been unobserved for so many ages, naturally led astronomers to examine, with greater accuracy, those small stars which had hitherto been generally neglected, or only considered as of use in determining the position of the planets. And these obervations have produced many other new discoveries in the celestial regions, by which our knowledge of the heavenly bodies, and of the immutable laws that govern the universe, are become much more extended; which is the great object of the science, and the source from which we may expect to derive such consequences as are of practical application, and the most useful to mankind.

Encouraged by his recent discoveries, Herschel continued his labours, both in the improvements of his telescopes, and his observations upon the heavenly bodies: the result of which has been the discovery of two other satellites, in addition to the five before known to belong to Saturn. The ring also of this planet has been more accurately observed, and the time of its revolution has been precisely ascertained, as well as that of the planet itself; which are found to be performed in nearly the same time. Such have been the discoveries of this indefatigable observer, beside various others equally important; but which your present stock of mathematical knowledge will not enable you so well to comprehend; which therefore I shall pass over for the present, and proceed to enumerate the discoveries of other astronomers.

I have before observed that the knowledge of another, and very remote planet, belonging to our system would naturally lead astronomers to examine with greater accuracy those small stars which had before been generally neglected; and the first important result deduced from such observations, was the discovery of a small planet in the space between Mars and Jupiter. This was first observed by Mr. Piazzi, of Palermo, on Jan. 1st, 1801, to which he has given the name of Ceres; the elements of which have been already described.

The next new planet was discovered by Dr. Olbers, of Bremen, March 28th, 1802, to which is given the name of Pallas; and another, by the same astronomer, was first observed March 29th, 1807. This latter is known under the name of Vesta, and is the next in order above Mars; but between the intervals of these two discoveries, another new planet was observed by Mr. Harding at the observatory at Lelienthal, near Bremen; who being engaged in the publication of some celestial charts, which should contain all the small stars, found by comparing one of them with the heavens at the date above mentioned, that he had omitted a small star, and which he therefore inserted in his map; but upon again comparing it with his chart four days afterwards, he perceived that it had changed its place; and, from further observations, ascertained it to be a planet similar to those observed by Olbers and Piazzi; and to which has been given the name of Juno.

All these planets revolve in the space between Mars and Jupiter; and what is very remarkable, the orbits of Ceres and Pallas intersect each other; and their mean distances are so nearly equal, that it is yet scarcely known which of the two is the highest in the system; though the latest calculations are in favour of Ceres. The inclination of the orbits of these four planets is much greater than that of any of the others, and their magnitudes extremely smaller; none of their diameters being supposed to exceed four hundred miles. These circumstances have induced Herschel to give them a different denomination, calling them asteroids; for which, however, he has been censured by other astronomers, on account of introducing a new term into this science, which appears to be both unnecessary and improper.

Having thus endeavoured to give you, in as familiar a manner as possible, a general idea of the most interesting parts of astronomy, I shall conclude the subject with Sir Isaac Newton's account of the Deity, given at the latter end of his Principia; which he considered as the most proper conclusion for a work that consists chiefly in an attempt to investigate the laws by which this great Being conducts his operations, and regulates the machine of the universe over which he presides.

"Seven primary planets revolve about the sun, in circles concentric with him, and with motions directed towards the same parts, and almost in the same plane. Ten moons revolve about the Earth, Jupiter, and Saturn, in circles concentric with them, with the same direction of motion, and nearly in the planes of the orbits of those planets. But it is not to be conceived, that mere mechanical causes could give birth to so many regular motions, since the comets range freely over all parts of the heavens in very eccentric orbits, and by this kind of motion pass with ease and rapidity through the orbs of the planets; and in their aphelions, where they move the slowest, and continue the longest, they recede to the greatest distances from each other, and thence suffer the least disturbance from their mutual attractions.

"This most beautiful system of the sun, planets, and comets, could only proceed from the counsel and dominion of an intelligent and powerful Being. And if the fixed stars are the centres of similar systems, these, being formed by the like wise counsels, must be all subject to the dominion of One; especially, since the light of the fixed stars is of the same nature with the light of the sun; and from every system light passes into all the other systems. And lest the systems of the fixed stars should, by their gravity, fall on each other mutually, he has placed them at immense distances from each other.

"This Being governs all things, not as the Soul of the World, but as Lord over all; and, on account of his dominion, he is wont to be called Lord God, or Universal Ruler. For God is a relative word, and has respect to servants; and Deity is the dominion of God, not over his own body, as those imagine who fancy him to be the Soul of the World, but over servants. The Supreme God is a Being eternal, infinite, and absolutely perfect; but a Being, however perfect, without dominion, cannot be said to be Lord God: for we say, my God, your God, the God of Israel, the God of Gods; my Eternal, your Eternal, the Eternal of Israel, the Eternal of Gods: but we do not say, my Infinite, or my Perfect; these are titles which have no respect to servants. The word God usually signifies Lord; but every Lord is not a God. It is the dominion of a spiritual Being which constitutes a God; a true, supreme or imaginary dominion, makes a true, supreme or imaginary God. And from his true dominion it follows, that the true God is a living, intelligent and powerful Being; and from his other perfections, that he is supreme or most perfect. He is eternal and infinite, omnipotent and omniscient; that is, his duration reaches from eternity to eternity, his presence from infinity to infinity; he governs all things, and knows all things that are or can be done. He is not eternity or infinity, but eternal and infinite; he is not duration or space, but he endures and is present. He endures for ever, and is every where present; and by existing always and every where, constitutes duration and space. Since every particle of space is always, and every indivisible moment of duration is every where, certainly the Maker and Lord of all things cannot be never and no where. Every soul that has perception is, though in different times, and in different organs of sense and motion, still the same indivisible person. There are given successive parts in duration, and co-existent parts in space, but neither the one nor the other in the person of a man, or his thinking principle; and much less can they be found in the thinking substance of God. Every man, so far as he is a thing that has perception, is one and the same man during his whole life, in all and each of his organs of sense. God is one and the same God, always and every where. He is omnipresent, not virtually only, but also substantially; for virtue cannot subsist without substance. In him are all things contained and moved; yet neither affects the other: God suffers nothing from the motion of bodies; bodies find no resistance from the omnipresence of God. It is allowed by all, that the Supreme God exists necessarily, and by the same necessity he exists always and every where. Hence also he is all similar, all eye, all ear, all brain, all arm, all power to perceive, to understand, and to act; but in a manner not at all human, in a manner not at all corporeal, in a manner utterly unknown to us. As a blind man has no idea of colours, so have we no idea of the manner by which the all-wise God perceives and understands all things. He is utterly void of all body and bodily figure, and can therefore neither be seen, nor heard, nor touched; nor ought he to be worshipped under the representation of any corporeal thing. We have ideas of his attributes, but what the real substance of any thing is, we know not. In bodies we see only their figures and colours, we hear only the sounds, we touch only their outward surfaces, we smell only the odours, and taste the savours, but their inward substances are not to be known, either by our senses, or by any reflex act of our minds; much less, then, have we any idea of the substance of God. We know him only by his properties and attributes, by his most wise and excellent contrivances of things, and by final causes; we admire him for his perfections, but we reverence and adore him on account of his dominion. For we adore him as his servants; and a God without dominion, providence, and final causes, is nothing else but Fate and Nature. Blind metaphysical necessity, which is certainly the same always and every where, could produce no variety or change. All that diversity of natural things which we find, suited to different times and places, could arise from nothing but the ideas and will of a Being necessarily existing. But, by way of allegory, God is said to see, to love, to rejoice, to fight, &c.

for all our notions of God are taken from the ways of mankind, by a certain similitude, which, though not perfect, has some likeness however.

"And thus much concerning God; to discourse of whom, from the appearances of things, certainly belongs to Natural Philosophy."

AN EXPLANATION

OF THE

PRINCIPAL TERMS MADE USE OF IN ASTROMOMY.

A.

Aberration, an apparent change of place in the fixed stars, which arises from the motion of the earth combined with the motion of light.

Achernar, a fixed star of the first magnitude in the constellation Eridanus.

Achronical rising or setting of a planet or star, is when it rises at sun-set, or sets at sun-rise.

Æras, certain periods of time, from which Chronologers and Astronomers begin their computations.

Aldebaran, a fixed star of the first magnitude, situated in the head of the constellation Taurus, and thence by some called the Bull's Eye.

Algeneb, a fixed star of the second magnitude in the right side of Perseus.

Algol, or Medusa's Head, a fixed star of the third magnitude in the constellation Perseus.

Alioth, the name of a fixed star in the tail of the great Bear.

Almacanters, certain imaginary circles, which, in every position of the globe, are supposed to be drawn parallel to the horizon.

Alpheta, or Lucida Corona, the name of a fixed star of the second magnitude, in the constellation called the Northern Crown.

Altar, or Ara, a southern constellation consisting of nine stars.

Altitude, the height of the sun, moon, or stars, above the horizon, reckoned upon a vertical circle, in degrees, minutes, &c.

Amphiscii, a name given to the inhabitants of the Torrid Zone, on account of their shadows falling at one time of the year towards the north, and at another time towards the south.

Amplitude, an arc of the horizon contained between the east or west point of the heavens, and the centre of the sun or a star, at the time of its rising or setting.

Andromeda, a northern constellation consisting of sixty-six stars.

Angle, the inclination or opening of two lines meeting in a point.

Anomaly (True), the distance of a planet in signs, degrees, &c. from that point of its orbit which is the farthest from the sun.

Anomaly (Mean), is that which would take place if the planet moved uniformly in the circumference of a circle.

Anser, the Goose, a northern constellation consisting of ten stars.

Anser Americanus, or Toucan, the American Goose, a southern constellation consisting of nine stars.

Antares, a fixed star of the first magnitude in the constellation Scorpio.

Antæci, a name given to those inhabitants of the earth, who live under the same meridian, and at equal distances from the equator, but on opposite sides of it.

Antecedentia, a motion of any of the heavenly bodies which is contrary to the order of the signs; as from Aries towards Pisces, &c.

Antinous, a northern constellation consisting of thirty-four stars.

Antipodes, those inhabitants of the earth who live diametrically opposite to each other, or walk feet to feet.

Apis, the Bee, a southern constellation composed of four stars.

APHELION, that point in the orbit of a planet in which it is at its greatest distance from the sun.

APOGEON, that point in the orbit of a planet in which it is at its greatest distance from the earth.

APSIDES, two points in the orbit of a planet in which it is at its greatest and least distance from the sun: The line joining those points is called the line of the Apsides.

AQUARIUS, a zodiacal constellation, which contains ninety-three stars.

AQUILA, or Vultur Volans, a constellation in the northern hemisphere, consisting of twelve stars.

ARCTURUS, a fixed star of the first magnitude, situated in the skirts of the constellation Bootes.

ARGO, the Ship, a southern constellation consisting of forty-eight stars.

ARMILLARY SPHERE, an instrument composed of the principal circles which are usually drawn upon an artificial globe.

ARIES, the Ram, a zodiacal constellation consisting of forty-six stars, into which the sun enters about the 20th of March, or the beginning of the spring quarter.

ASCII, the inhabitants of the torrid zone; so called, because the sun being twice a year in their zenith, their bodies at those times cast no shadow.

ASCENSIONAL DIFFERENCE, an arc of the equinoctial contained between that point of it which rises with the sun, moon, or star, and that which comes to the meridian with them; or it is the time the sun rises or sets before or after six o'clock.

ATMOSPHERE, that collection of vapours, or body of air, which surrounds or encompasses the earth.

ATTRACTION, a property of matter, by which bodies are made to approach towards each other, without any sensible agent either drawing or impelling them.

AURORA, the morning twilight, which begins to appear when the sun is about eighteen degrees below the horizon.

AURIGA, a northern constellation containing forty-six stars.

AXIS of the earth, or of a planet, an imaginary line passing through the centre from one pole to the other; or that round which they are supposed to perform their diurnal rotations.

AZIMUTHS, great circles which pass through the zenith and nadir, and are perpendicular to the horizon.—The Azimuth of any celestial object is an arc of the horizon, contained between the east or west point of the heavens, and a vertical circle passing through the centre of that object.

B.

BASILICUS, or Cor Leonis, a fixed star of the first magnitude in the constellation Leo.

BEARS, two constellations in the northern hemisphere, called Ursa Major and Ursa Minor; the first consisting of one hundred and five stars, and the second of twelve: The north pole star is in the tail of the little Bear.

BERENICES HAIR, a northern constellation consisting of twenty-four stars.

BETELGUESE, a star of the second magnitude in the east shoulder of Orion.

BISSEXTILE, or Leap-Year; so called by the Romans, on account of their reckoning the 6th day of the calends of March twice over.

BOOTES, a northern constellation consisting of fifty-three stars; one of which, Arcturus, in the skirts of his coat, is of the first magnitude.

C.

CAMELOPARDALUS, a northern constellation composed of twenty-three stars.

CANCER, the Crab, one of the signs of the ecliptic, consisting of seventy-five stars; into which the sun enters about the 21st of June, or upon our longest day.

CANIS MAJOR, and CANIS MINOR, the Great and Little Dog; two constellations in the southern hemisphere, the first consisting of twenty-nine stars, and the second of fourteen.

CANOPUS, a star of the first magnitude in the constellation Argo.

CAPELLA, a fixed star of the first magnitude, in the left shoulder of the constellation Auriga.

CAPRICORNUS, the Goat, one of the signs of the ecliptic, consisting of fifty-eight stars; into which the sun enters about the 21st of December, or upon our shortest day.

CARDINAL POINTS, the east, west, north, and south points of the compass.

CARDINAL POINTS of the ecliptic, the first points of the signs Aries, Cancer, Libra, and Capricorn.

CASSIOPEIA, a constellation in the northern hemisphere consisting of fifty-two stars.

CAUDA LUCIDA, the Lion's Tail, a fixed star of the second magnitude in the constellation Virgo.

CENTAUR, a southern constellation consisting of thirty-six stars.

CENTRIFUGAL FORCE, that force by which any revolving body endeavours to fly off from the centre of motion, in a tangent to the circle which it describes.

CENTRIPETAL FORCE, that force by which any revolving body is made to tend towards the centre of its orbit.

CEPHEUS, a constellation in the northern hemisphere consisting of forty stars.

CERBERUS, a northern constellation composed of nine stars.

CERES, one of the last new planets, the seventh in order from the sun.

CETUS, the Whale, a southern constellation which contains eighty stars.

CHARLES'S OAK, a southern constellation composed of thirteen stars.

CHARLES'S WAIN, seven remarkable stars in Ursa Major, or the Great Bear.

CHAMELION, a southern constellation composed of ten stars.

CHRYSTALLINE HEAVENS, in the Ptolemaic system, two solid orbs, by means of which the ancients attempted to account for the apparent motion of the fixed stars.

COMETS, certain erratic bodies belonging to our system, which move round the sun in very eccentric orbits, and are principally distinguished from the planets by their tails, or some hairy or nebulous appearance.

COR CAROLI, Charles's Heart, an extra-constellated star in the northern hemisphere, situated between Coma Berenices and Ursa Major, so called in honour of King Charles the First; some make it a constellation consisting of three stars.

CORONA BOREALIS, the Northern Crown, a constellation in the northern hemisphere consisting of eleven stars.

CORONA MERIDIONALIS, the Southern Crown, a southern constellation composed of twelve stars.

COLURES, two great circles, or meridians, one of which passes through the solstitial points Cancer and Capricorn, and the other through the equinoctial points Aries and Libra.

CONJUNCTION, is when two stars, seen from the sun or the earth, appear in the same point of the heavens, or answer to the same degree of the ecliptic.

CONSTELLATION, a number of stars lying in the neighbourhood of each other, which Astronomers, for the sake of remembering with more ease, suppose to be circumscribed by the outlines of some animal, or other figure.

COSMICAL rising or setting of a planet or star, is when it rises with the sun in the morning, or sets with him in the evening.

CONSEQUENTIA, a motion of the planets according to the order of the signs; as from Aries towards Taurus, &c.

CORVUS, the Crow, a southern constellation consisting of eight stars.

CRATER, the Cup, a southern constellation composed of eleven stars.

CROSIERS, four stars in the form of a cross, which are of use to sailors in finding the south pole.

CULMINATING, a term applied to the sun or a star when it comes to the meridian of any place.

CYCLE of the moon, a revolution of nineteen years, in which time the conjunctions and lunar aspects are nearly the same as they were nineteen years before.

CYGNUS, the Swan, a constellation in the northern hemisphere, consisting of seventy-three stars.

D.

DAY (Natural), that portion of time in which the earth completes an entire revolution upon its axis.

DAY (Artificial), the time between the sun's rising and setting; to which is opposed night, or the time between his setting and rising.

DAY (Astronomical), the time between two successive transits of the sun's centre over the same meridian; which always begins and ends at noon.

DECLINATION of the sun, moon, or stars, is their distance north or south from the equator, reckoned in degrees, minutes, &c. upon a circle which is perpendicular to it.

DICHOTOMIZED, a term applied to the moon when she is in her quadratures, and appears only half illuminated.

DEGREE, the three hundred and sixtieth part of a circle, or the thirtieth part of a sign.

DELPHINUS, the Dolphin, a constellation in the northern hemisphere consisting of eighteen stars.

DIRECT, a planet is said to be direct, when it moves according to the order of the signs; as from Aries towards Taurus, &c.

DISC of the sun, or moon, is its round face, which, on account of the great distance of the object, appears flat, or like a plane surface.

DIGIT, in Astronomy, the twelfth part of the sun's diameter, which is often used in the calculation of eclipses.

DIURNAL, of or belonging to the day; thus, the diurnal motions of the planets, are the spaces they move through in a day.

DISTANCE, in Astronomy, is sometimes denoted by a straight line, and sometimes by an arc of a circle; the latter of which is the case when we speak of the distance of two stars from each other.

DOMINICAL LETTER, one of the first seven letters of the alphabet; which is usually marked in red, and employed in the Almanack for distinguishing the Sundays throughout the year.

DRACO, or the Dragon, a northern constellation, consisting of forty-nine stars.

DRAGON'S HEAD, or the Ascending Node, is the northern intersection of the moon's orbit with the ecliptic; which is marked thus ☊.

Dragon's Tail, or the Descending Node, is the southern intersection of the moon's orbit with the ecliptic; which is marked thus ☋.

E.

Earth, the globe which we inhabit; one of the seven planets, and the third in order from the sun.

Eccentricity, the distance between the centre of an ellipsis and either of its foci.

Eclipse of the sun, an obstruction of his light, occasioned by the interposition of the dark body of the moon between him and our sight.

Eclipse of the moon, a deprivation of her light, occasioned by the interposition of the earth between the sun and moon.

Ecliptic, a great circle of the sphere, in which the sun always appears to move; so called, because eclipses generally happen when the moon is in or near this circle. The obliquity of the ecliptic is the angle it makes with the equator, which is now about twenty-three degrees twenty-eight minutes.

Elevation of the Pole, is an arc of the meridian contained between the pole and the horizon; which is always equal to the latitude of the place, or the distance of the zenith from the equator.

Elongation, the angular distance of a planet from the sun, as it appears to a spectator upon the earth.

Elements, in Astronomy, the requisites necessary to determine the theory of a planet, in order to calculate its position, motion, &c.

Ellipsis, a figure formed by cutting a cone obliquely to its axis: it is in a curve of this kind that the planets move round the sun, and the satellites round their primaries.

Emersion, the time when any planet which is eclipsed begins to recover its light again.

Epact, the moon's age at the end of the year, or the difference between the solar year and the lunar one.

Epoch, the same as Æra, a period from whenee Chronologers and Astronomers begin their computations.

EQUATIONS, certain quantities by which we estimate the inequalities in the motion of a planet: The moon, being subject to many irregularities, has a great number of equations.

EQUATION of time, the difference between equal time and apparent, or that shown by a perfectly true clock and a sundial.

EQUATOR, a great circle which separates the northern from the southern hemisphere, and being referred to the heavens s called the EQUINOCTIAL.

EQUINOXES, the two points where the ecliptic cuts the equator; so called, because, when the sun is in either of these situations, the days and nights are equal to each other.

EQUULUS, or Equus Minor, the Colt, a constellation in the northern hemisphere consisting of twelve stars.

ERIDANUS, the river, a southern constellation containing seventy-two stars.

EVECTION, an inequality in the motion of the moon, by which, at her quarters, her mean place differs from her true one by about two degrees and a half more than at her conjunction and opposition.

ETHER, a fine subtile fluid, which is supposed to fill the whole celestial space between the heavenly bodies and our atmosphere.

F.

FOCI of an ellipsis, two points in the longest or transverse axis, on each side of the centre; from each of which if any two right lines be drawn to meet each other in the periphery, their sum will be always equal to the transverse axis.

G.

GALAXY, or the Milky-way, a large irregular zone or band of light which encompasses the heavens.

GEMINI, the Twins, a zodiacal constellation consisting of ninety-four stars.

GEOCENTRIC place of a planet, is that position which it has when seen from the earth.

GEORGIUM SIDUS, a new planet lately discovered by Dr. Herschel, being the eleventh in order from the sun, and the most distant of any in the system.

GIBBOUS, a term used in reference to the enlightened parts of the moon, whilst she is moving from the first quarter to the full, and from the full to the last quarter, on account of the dark parts appearing falcated, or horned, and the light ones convex.

GOLDEN NUMBERS, a series of numbers proceeding from one to nineteen, which are used in the almanack for determining the times of new and full moons.

GREGORIAN YEAR, so called from Pope Gregory XIII. who reformed the calendar in the year 1582; which reformation was not used in England till 1752.

GREYHOUNDS, a northern constellation consisting of twenty-four stars.

GRUS, the Crane, a southern constellation composed of fourteen stars.

H.

HELIACAL rising of a star, is when it emerges from the sun's rays, and appears above the horizon before him in the morning.

HELIACAL setting of a star, is when it is so hid in the sun's beams, as not to be seen above the horizon after him in the evening.

HELIOCENTRIC place of a planet, is that in which it would appear to a spectator placed in the sun.

HEMISPHERE, the half of a globe or sphere when it is cut through its centre in the plane of one of its great circles.

HERCULES, a northern constellation composed of ninety-two stars.

HESPERUS, a name given to the planet Venus, when she appears in the evening.

HETEROSCII, a name given to the inhabitants of the temperate zones, because their shadows at noon always fall one way.

HIRUNDO, the Swallow, a southern constellation composed of eleven stars.

HORIZON (Sensible), a circle which separates the visible hemisphere from the invisible one, or that which is the boundary of our sight.

HORIZON (Rational), a great circle parallel to the former, which passes through the centre of the earth, and whose two poles are the zenith and nadir.

HORIZONTAL, something relating to the Horizon, or that which is taken in, or on a level with the Horizon.

HOUR CIRCLES, the same with the meridians; or great circles which pass through the poles of the world, and are perpendicular to the equator.

HOUR, the twenty-fourth part of a natural day, which Astronomers always begin to reckon from noon.

HYDRA, a southern constellation, composed of fifty-three stars.

HYPOTHESIS, a supposition, a system formed upon some principle which has not been proved.

I.

IMMERSION, the moment when an eclipse begins, or when a planet enters into the dark shadow.

INCLINATION, the angle which the orbit of one planet makes with that of another.

INDEFINITE, or Indeterminate, that to which the human mind cannot fix any certain bounds or limits.

INDUS, a southern constellation composed of twelve stars.

INFERIOR PLANETS, are those that move at a less distance from the sun than the earth; which are Mercury and Venus.

INGRESS, is the sun's entrance into any sign or other part of the ecliptic.

INTERCALARY DAY, the odd day, which is made up of the six hours that take place every fourth or leap-year.

JULIAN YEAR, the account of time instituted by Julius Cæsar, which is now called the old style.

JUNO, one of the last newly discovered planets, and the sixth in order from the sun.

JUPITER, the largest planet in our system, and the fifth in order from the sun.

L.

LATITUDE of a place, is its distance from the equator, reckoned in degrees, minutes, &c. upon the arc of a great circle which is perpendicular to it.

LATITUDE of a star or planet, is its distance from the ecliptic, reckoned in degrees, minutes, &c. upon the arc of a great circle which is perpendicular to it.

LEAP YEAR, the same with Bissextile; so called from there being a day more in that year than in a common one.

LEO, the Lion, a zodiacal constellation consisting of ninety-one stars.

LEO MINOR, the Little Lion, a northern constellation consisting of twenty stars.

LESSER CIRCLES of the sphere, are those whose planes do not pass through its centre.

LEPUS, the Hare, a southern constellation composed of twenty-five stars.

LIBRA, the Balance, one of the twelve signs of the zodiac, into which the sun enters about the 20th of September, or the beginning of autumn.

LIBRATION, an apparent irregularity of the moon's motion, which makes her appear to librate about her axis in such a manner that the parts of her eastern and western limbs become visible and invisible alternately.

LIZARD, a northern constellation, consisting of twelve stars.

LONGITUDE of a place, is its distance east or west from the first meridian, reckoned in degrees, minutes, &c. upon the equator.

LONGITUDE of a star or planet, is its distance from the first point of Aries, reckoned in degrees, minutes, &c. upon the ecliptic.

LUCIDA LYRA, a fixed star of the first magnitude in the constellation Lyra.

LUCIFER, the morning star, Venus, so called when she is in the east, and rises before the sun.

LUMINARIES, the sun and moon, so called by way of eminence, on account of their extraordinary lustre, and the great light they afford us.

LUNAR ASPECTS, are those which the moon makes with any of the other planets; as when she comes in opposition, trine, quartile, &c.

LUNATION, a lunar synodical month, or the space of time between one new moon and another, which is generally about twenty-nine days, twelve hours, forty-four minutes and three seconds; being greater than the periodical month by two days and five hours.

LUNI-SOLAR YEAR, a period made by multiplying the cycle of the moon 19 by that of the sun 28.

LUPUS, the Wolf, a southern constellation consisting of thirty-six stars.

LYNX, a northern constellation consisting of fifty-five stars.

LYRA, a constellation of the northern hemisphere, consisting of twenty-four stars.

M.

MACULÆ, dark spots, appearing on the face of the sun, moon, and some of the planets, being contra-distinguished from Faculæ, which are bright or shining spots, that, by means of the Telescope, are sometimes to be seen on the face of the sun, &c.

MAGNITUDES; the stars are divided into six sizes, or classes; of which the brightest are called stars of the first magnitude; the next in brightness to these, stars of the second magnitude; and so on.

MARS, a primary planet belonging to the solar system, which is the fourth in order from the sun, and whose magnitude is about four times less than that of the earth.

MEAN motion of a planet, is that which would take place if it moved in a perfect circle, and equally every day.

MEDIUM COELI, the mid-heaven, that degree of the ecliptic which is upon the meridian at any time of the day or night.

MERCURY, a primary planet, the first in order from the sun, and whose magnitude is about fifteen times less than that of the earth.

MERIDIAN, a great circle of the sphere, which passes through the zenith and poles, and is perpendicular to the horizon; it is so called, because when the sun is upon this circle it is always mid-day or noon.

METONIC YEAR, the same with the cycle of the moon; a period invented by Meton, a Greek philosopher, who lived in the eighty-sixth olympiad, or about four hundred and thirty years before Christ.

MICROMETER, an instrument by which the apparent magnitudes of objects, viewed through telescopes or microscopes, are measured with great exactness.

MICROSCOPE, an optical instrument, by means of which very minute objects are represented much larger, and viewed distinctly at small distances.

MINUTE, the 60th part of an hour in time, or of a degree in motion.

MONOCEROS, a southern constellation, consisting of thirty-two stars.

MONS MÆNALUS, a northern constellation, consisting of eleven stars.

MONTH, (lunar or periodical,) a period of about twenty-seven days, seven hours and forty-three minutes; which is the time the moon is in passing from one point of her orbit to the same point again.

MONTH, (synodical,) a period of about twenty-nine days and a half; which is the time between one conjunction of the sun and moon and another.

MONTH, (solar, or calendar,) the time the sun takes to move through one of the signs of the zodiac; which, at a mean, is about thirty days and a half.

MOON, a secondary planet, or satellite, attending the earth, which she regards as the centre of her motion.

MUSCA, the Fly, a northern constellation, consisting of six stars.

N.

NADIR, that point in the heavens which is directly opposite to the zenith, or immediately under our feet.

NEBULÆ, clusters of small stars which have been discovered, by the telescope, in different parts of the heavens; and are so called from their cloudy appearance.

NOAH'S DOVE, a southern constellation, composed of ten stars.

NOCTURNAL ARC, is that space of the heavens which the sun apparently describes from the time of his setting to the time of his rising.

NODES, the two points where the orbit of a planet intersects the plane of the ecliptic.

NONAGESIMAL DEGREE, the ninetieth degree, or highest point of the ecliptic, at any given time of the day or night.

NORTHERN SIGNS of the ecliptic, are those six which lie to the north of the equinoctial; as Aries, Taurus, Gemini, Cancer, Leo, and Virgo.

NUCLEUS, a term used by some Astronomers for the head of a comet, and by others for the central parts of the planets.

NUTATION of the earth's axis, a libratory motion occasioned by the attraction of the sun and moon upon the protuberant matter of the equator.

O.

OBLIQUE ASCENSION, is an arc of the equinoctial contained between the first degree of Aries, and that point of it which rises with the centre of the sun or a star.

OBLIQUE SPHERE, is that position of the globe, in which either of the poles are elevated above the horizon any number of degrees less than ninety.

OCCULTATION, is when a star or planet is hid from our sight by the interposition of the moon, or some other planet.

OCTANT, an aspect of the planets when they are forty-five degrees distant from each other.

OPHIUCHUS, or Serpentarius, a northern constellation, consisting of sixty-seven stars.

OPPOSITION, an aspect of the stars or planets when they are a hundred and eighty degrees distant from each other; which in the Ephemeris is marked ☍.

ORBIS MAGNUS, the orbit of the earth, which is described by its annual revolution round the sun.

ORBIT of a planet, the curve or path which it describes in its revolution round the sun.

ORION, a southern constellation, consisting of ninety-three stars.

P.

PALLAS, one of the newly discovered planets, and the seventh in order from the sun.

PARALLAX, the difference between the places of any celestial object, as seen from the surface of the earth and from its centre.

PARALLAX of the earth's annual orbit, is the angle at any planet which is subtended by the distance between the sun and earth; or it is that change of place in the planets, which arises from their being seen from different points of space, as the earth moves round the sun.

PARALLELS of latitude, small circles of the sphere, which are drawn parallel to the equator.

PAVO, the Peacock, a southern constellation, composed of fourteen stars.

PEGASUS, a constellation in the northern hemisphere, consisting of sixty-seven stars.

PENDULUM, a body that swings backwards and forwards about a fixed point; and which, on account of its equal vibrations, is made use of for measuring time.

PENUMBRA, a faint shadow which accompanies an eclipse, and occasions a partial obscurity of the body to that part of the earth on which it falls.

PERIOECI, those inhabitants of the earth who live under the same parallels of latitude, but on opposite sides of the meridian.

PERIGEON, that point of a planet's orbit in which it is at its least distance from the earth.

PERIHELION, that point of a planet's orbit in which it is at its least distance from the sun.

PERIOD, a certain length of time after which eclipses, and other celestial phænomena, return again in the same manner as before.

PERIPHERY, the circumference of a circle, ellipse, or any other regular figure.

PERISCII, the inhabitants of either of the frozen zones; so called, because their shadows go round them for six months, or fall towards opposite points of the compass.

PERSEUS, a constellation in the northern hemisphere, consisting of sixty-seven stars.

PHASES, the several appearances of the moon and planets, according as a greater or less part of their illuminated hemispheres are presented to our sight.

PHOENIX, a southern constellation, consisting of thirteen stars.

PHOSPHOR, a name given to Venus when she is a morning star.

PROCYON, a fixed star of the second magnitude, in the constellation Canis Minor.

PISCES, the Fishes, a zodiacal constellation, consisting of a hundred and ten stars.

PISCES VOLANS, the flying Fish, a southern constellation, consisting of seven stars.

PLANETS, (Primary,) those bodies, in our system, that regard the sun as the centre of their motions; the number of which is eleven, Mercury ☿, Venus ♀, the Earth ⊖, Mars ♂, Vesta, Juno, Ceres, Pallas, Jupiter ♃, Saturn ♄ and Uranus ♅.

PLANE, in astronomy, is frequently used for an imaginary surface, which is supposed to cut and pass through solid bodies; and in this sense we are to understand the plane of a planet's orbit.

PLANETARIUM, an instrument made use of for showing the phænomena of the planets.

PLEIADES, seven remarkable stars in the constellation Taurus.

POLAR CIRCLES, two small circles of the sphere, twenty-three degrees and a half distant from the poles; that about the north pole being called the arctic circle, and the one about the south pole the antarctic circle.

POLE STAR, a star of the second magnitude, in the tail of the Little Bear; so called from its being situated near the north pole of the world.

POLES of the World, those two points which are at the extremities of the earth's axis; or, when referred to the heavens, the two points directly over them.

PROJECTILES, such bodies, as being put into motion by any particular force, continue to move with a certain velocity, either in a straight line, or a curve, according to circumstances; such as a stone thrown from a sling, an arrow from a bow, or a ball from a gun.

PRIMUM MOBILE, the first mover, an immense sphere, which, in the Ptolemaic system, was supposed to turn round the earth, as a centre, every twenty-four hours, and to carry with it the sun, moon, and planets.

PRECESSION of the equinoxes, a slow motion of the two points where the equator intersects the ecliptic, which are found to go backwards about fifty seconds a year.

Q.

QUADRAGESIMA, the first Sunday in Lent; so called because it is about the fortieth day before Easter: and for a like reason, the three preceding Sundays are called Quinquagesima, Sexagesima and Septuagesima.

QUADRANT, the fourth part of a circle; or an instrument made use of for measuring angles, and taking the altitudes of the celestial bodies.

QUADRATURES, or quarters; those phases of the moon which take place between the conjunction and opposition, and between the opposition and conjunction: one being called the first quarter, and the other the third.

QUARTILE, an aspect of the planets when they are ninety degrees, or a quarter of the zodiac distant from each other; which in an Ephemeris is denoted by □.

QUIESCENT, the state of a body which is at rest, or in opposition to motion.

R.

REFRACTION, is that variation which the rays of light suffer in passing through mediums of different densities; which occasions the heavenly bodies, when viewed obliquely through the atmosphere, to appear at a greater height above the horizon than they really are.

REGULUS, a fixed star of the first magnitude in the heart of the constellation Leo.

RIGEL, a fixed star of the first magnitude in the left foot of Orion.

REFLEXION, is the return of the rays of light, after approaching so near the surface of bodies as to be repelled or driven backwards.

REPULSION, that property in bodies, by which, if they are placed just beyond the sphere of their attraction of cohesion, mutually fly from each other.

RETROGRADE, an apparent motion of the planets in some parts of their orbits, when they seem to go backwards, or contrary to the order of the signs.

Revolution, is that motion by which the heavenly bodies, in a certain time, return again to the same points of their orbits.

Right Ascension, is that degree of the equator which comes to the meridian with the sun, moon, or star, reckoning from the first point of Aries.

Rotation, the motion of any heavenly body round its axis.

S.

Sagittarius, the Archer, a zodiacal constellation, consisting of forty-eight stars.

Sagitta, the Arrow, a northern constellation, consisting of thirteen stars.

Satellites, secondary planets, or moons; which revolve round the primary planets in the same manner as those primaries revolve round the sun.

Saturn, a primary planet, the sixth in order from the sun; and whose magnitude is about a thousand times greater than that of the earth.

Scorpio, a zodiacal constellation, consisting of forty-four stars.

Second, the sixtieth part of a minute, either of time or motion.

Secondary circles of the sphere, are those circles which pass through the poles of some great circle: thus the meridian and hour circles are secondaries to the equinoctial, &c.

Serpens, the Serpent, a northern constellation, consisting of fifty stars.

Serpentarius, a northern constellation, composed of sixty-seven stars.

Sextans Uraniæ, a southern constellation, consisting of four stars.

Sextile, an aspect of the heavenly bodies, when they are sixty degrees distant from each other; and which is denoted in Ephemeris by ✱.

Sidereal, of or belonging to the stars or planets.

Sidereal Year, is that space of time which the sun takes in moving through the ecliptic, from any fixed star to the same star again.

SIGNS, the twelve constellations of the zodiac, Aries ♈, Taurus ♉, Gemini ♊, Cancer ♋, Leo ♌, Virgo ♍, Libra ♎, Scorpio ♏, Sagittarius ♐, Capricornus ♑, Aquarius ♒ and Pisces ♓.

SOBIESKI'S SHIELD, a northern constellation, consisting of eight stars.

SOLSTITIAL POINTS, are the two signs of the zodiac, Cancer and Capricorn, at which the ecliptic touches the tropics, and into which the sun enters on our longest and shortest days.

SOUTHERN FISH, a constellation in the southern hemisphere, composed of fifteen stars.

SOUTHERN TRIANGLE, a constellation in the southern hemisphere, consisting of five stars.

SOUTHING of the stars, the time when they culminate or come to the meridian.

SPICA VIRGINIS, a fixed star of the first magnitude, in the constellation Virgo.

STARS, (fixed,) those bodies which shine by their own light, and are not subject to motion.

STATIONARY, a planet is said to be stationary when it has no apparent motion.

STYLE, the manner of reckoning time from some particular period or remarkable event.

SUPERIOR PLANETS, are those that move at a farther distance from the sun than the earth; which are Mars, Vesta, Juno, Pallas, Ceres, Jupiter, Saturn and Uranus.

SYNODICAL MONTH, the space of time from any new moon to the following one; which is, at a mean, twenty-nine days, twelve hours and forty-five minutes.

SIRIUS, a fixed star of the first magnitude, in the constellation Canis Major; which is the brightest in the heavens.

SYSTEM, a number of bodies revolving round a common centre, as the planets and comets move round the sun.

SYZYGIES, those points of the moon's orbit, in which she is at the time of her new and full.

T.

TAURUS, the Bull, a zodiacal constellation, consisting of one hundred and nine stars.

TELESCOPIC STARS, those stars which are only discoverable by means of a telescope.

TEMPERATE ZONES, those parts of the earth contained between the tropics and polar circle.

THEORY, any doctrine which terminates in speculation, without considering its practical uses and application.

TORRID ZONE, that part of the earth which is contained between the two tropics.

TRANSIT, is the passing of one celestial body before another, so as to render it invisible.

TRIGONUS MAJOR, the Great Triangle, a northern constellation, consisting of ten stars.

TRIGONUS MINOR, the Little Triangle, a northern constellation, consisting of five stars.

TRINE, an aspect of the planets, when they are a hundred and twenty degrees distant from each other; which in an Ephemeris is denoted by △.

TROPICS, two small circles of the sphere which are parallel to the equator, and twenty-three degrees twenty-eight minutes distant from it.

TWILIGHT, is that faint light which we perceive before the rising of the sun, and after his setting; being occasioned by the refraction of the earth's atmosphere.

V.

VECTOR (Radius), a line supposed to be drawn from any planet to the sun, which, moving with the planet, describes equal areas in equal times.

VENUS, a primary planet, the second in order from the sun; whose magnitude is about one-ninth less than that of the earth.

VERTICAL CIRCLES, the same as Azimuth Circles, or such as are drawn perpendicular to the horizon.

VESTA, one of the small new planets lately discovered, and revolving next above Mars in our system.

VIRGO, the Virgin, a zodiacal constellation, consisting of ninety-three stars.

URSA MAJOR, the Great Bear, a northern constellation, consisting of one hundred and five stars; sometimes also called Charles's Wain.

URSA MINOR, the Little Bear, a northern constellation near the pole, consisting of twelve stars.

VULPES, the Fox, a northern constellation, consisting of twenty-nine stars.

URANUS, or Georgium Sidus, the new planet discovered by Herschell; which is the highest of any in our system.

X.

XIPHIAS, the Sword-fish, a southern constellation, consisting of seven stars.

Y.

YEAR, the space of time taken up by the sun in going through the twelve signs of the zodiac.—See SIDEREAL YEAR, &c.

Z.

ZENITH, that point of the heavens which is perpendicularly over our heads.

ZODIAC, a zone or girdle, surrounding the heavens, of about eighteen degrees broad, in the middle of which is the ecliptic; and in which the orbits of all the planets are included.

ZONE, a division of the sphere, contained between any two parallels of latitude.

THE END.

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