LECTURES

ON

EXPERIMENTAL PHILOSOPHY

Vol. II.

LECTURES

ON

EXPERIMENTAL PHILOSOPHY,

&c. &c.

LONDON
PRINTED BY THOMAS DAVISON, WHITEFRIARS.

LECTURES

ON

EXPERIMENTAL PHILOSOPHY,

ASTRONOMY,

AND

CHEMISTRY:

INTENDED CHIEFLY

For the Use of Students and Young Persons.

BY G. GREGORY, D.D.

LATE VICAR OF WEST HAM; DOMESTIC CHAPLAIN TO THE LORD BISHOP OF LLANDAFF; AND AUTHOR OF THE ECONOMY OF NATURE, &c. &c.

IN TWO VOLUMES.

VOL. I.

SECOND EDITION, CORRECTED AND IMPROVED.

LONDON:

PRINTED FOR LONGMAN, HURST, REES, ORME, AND BROWN; BALDWIN, CRADOCK, AND JOY; SCATCHERD AND LETTERMAN; G. AND W. B. WHITTAKER; AND SHERWOOD, NEELY, AND JONES.

1820.

PREFACE.

THE object of this publication is, to afford a useful companion to such Students as may attend Lectures in the Universities, at the Royal Institution, or elsewhere; and also to enable the Masters of private Seminaries, with a very moderate Apparatus, occasionally to indulge their pupils with a practical Course of Lectures on one or all of the important branches of Experimental Philosophy, Astronomy, and Chemistry.

Having published some years ago "The Economy of Nature," the author thinks it necessary to state, that both the plan and arrangement of that work are essentially different from those of the present. The Economy of Nature does not contain Astronomy, nor, in fact, Chemistry, as a distinct science; on the other hand, a very large portion of that work is occupied with Mineralogy and Physiology, which in this are purposely omitted. Even the subjects which are common to both will be found to be differently treated in these Lectures.

February 20, 1808.

PREFACE

TO THE

SECOND EDITION.

THE first Edition of these Lectures having experienced a very extensive circulation, the Proprietors have thought it their duty to procure for the present such an entire and cautious revision as should render it still more worthy public favour.

The whole of the first volume, and so much of the second as relates to Astronomy, has been carefully examined by a gentleman whose different works on Mathematics and several departments of Natural Philosophy have acquired a high reputation. He has made numerous additions and improvements, correcting errors, and carefully introducing as he went along, the most important discoveries both of English and of continental Philosophers, down to the close of 1819.

The chemical department has, in like manner, undergone the careful revision of a gentleman eminent in the science of Chemistry. So numerous and important have been the accessions to this region of human knowledge, in the course of the last twelve years, that a cautious revision has, in fact, included the entire re-composition of a considerable portion of the second volume.

The Proprietors have every reason to believe that the improvements thus made to the Lectures will considerably augment their utility: and they humbly yet confidently anticipate the reward of an enlightened public, for the expense they have incurred by engaging gentlemen of such acknowledged competence to make the volumes exhibit a correct yet popular view of the present state of Experimental and Chemical Philosophy.

July, 1820.

DIRECTIONS FOR PLACING THE PLATES.

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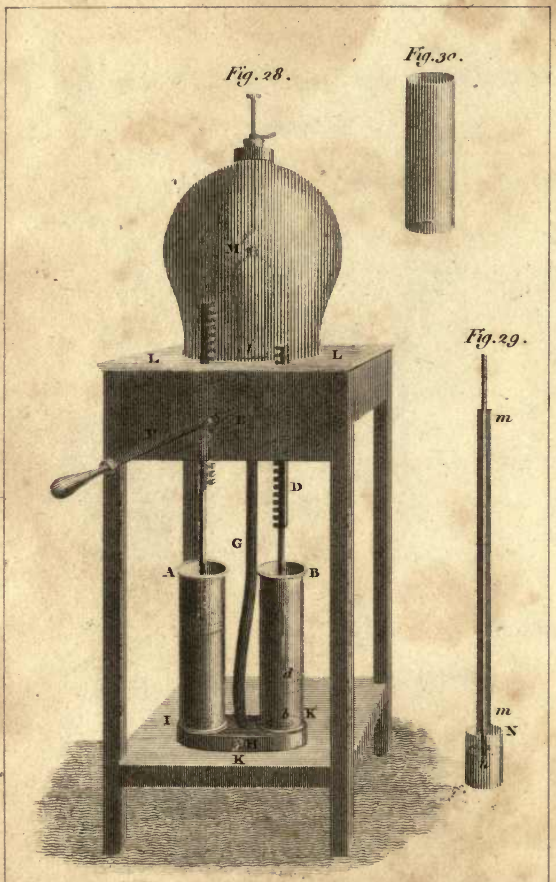

J. Farey Junr. del. S. Porter sculp.

HYDROSTATICS & HYDRAULICS. PL.V.

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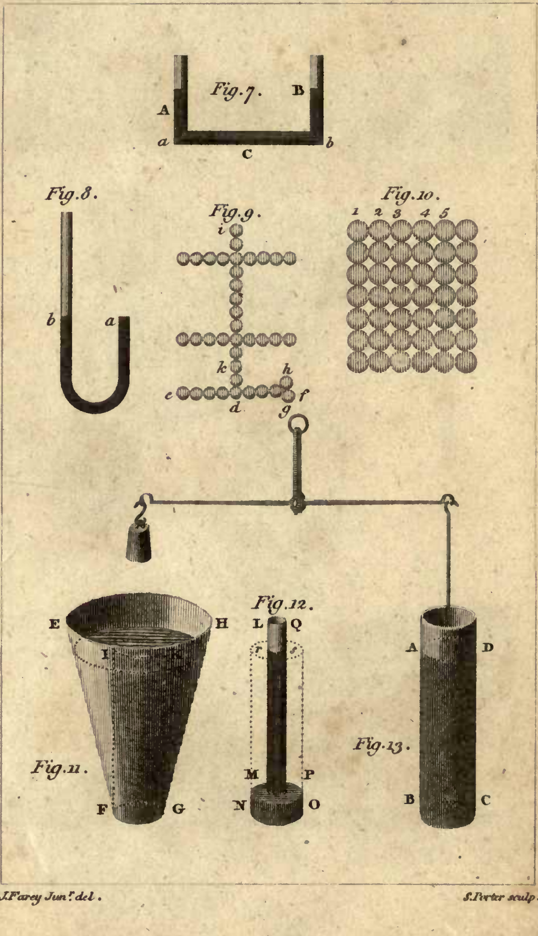

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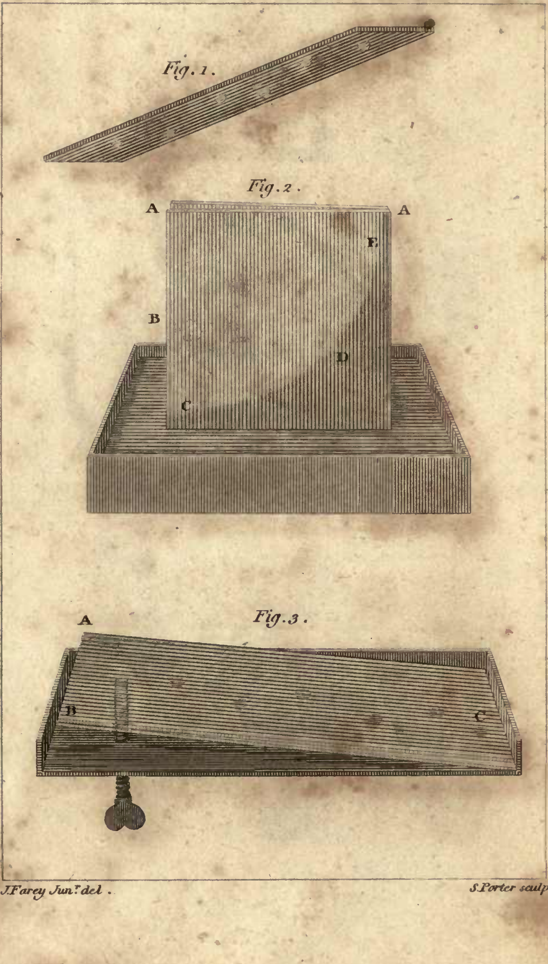

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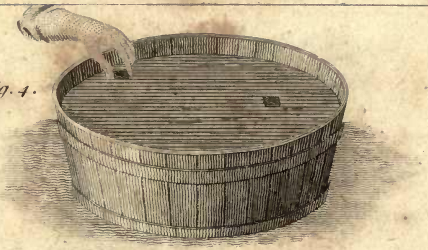

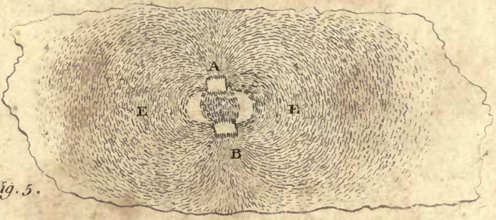

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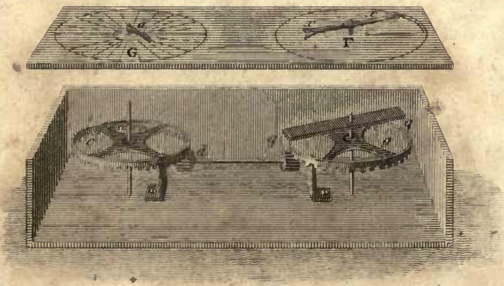

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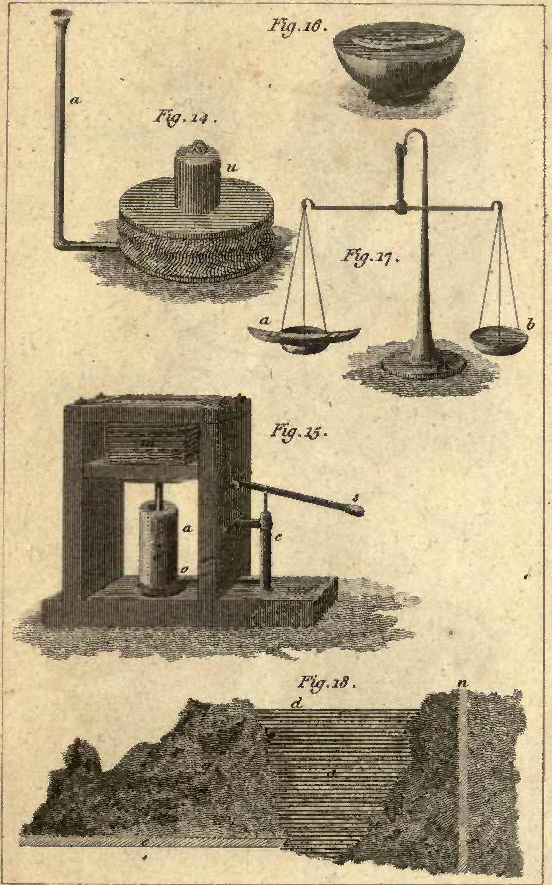

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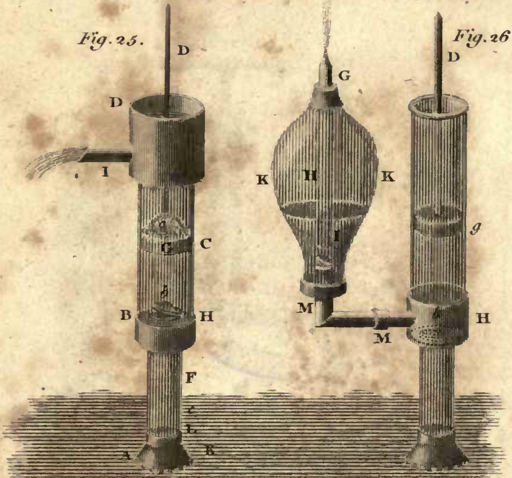

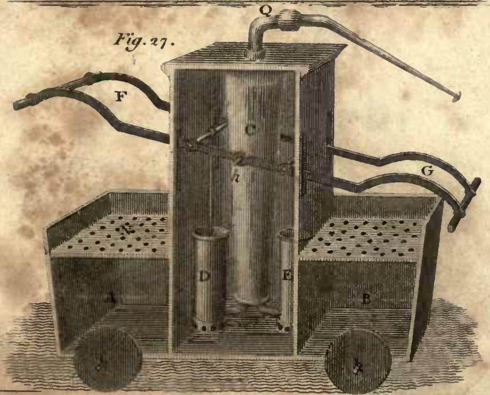

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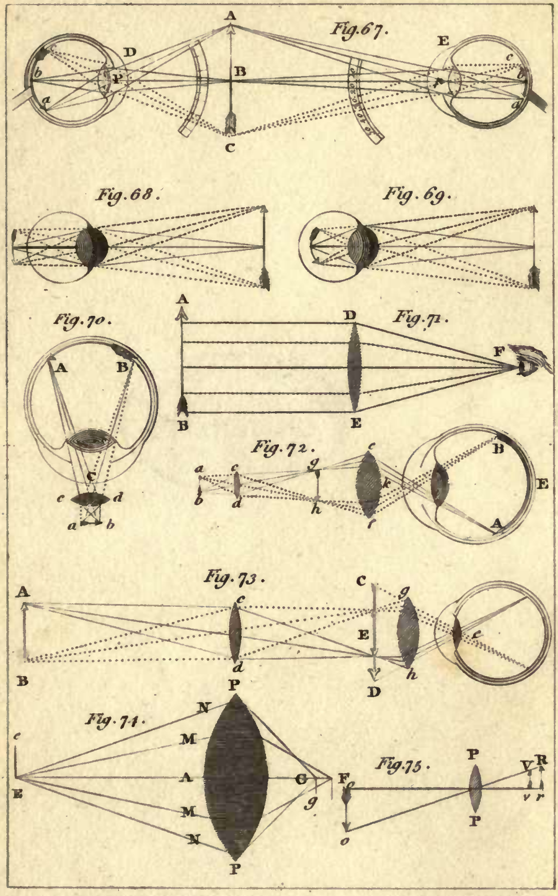

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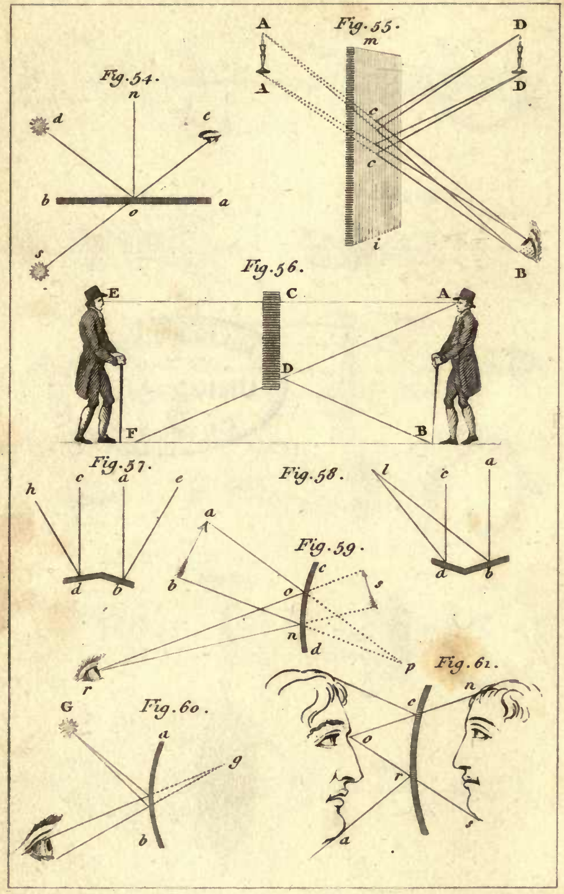

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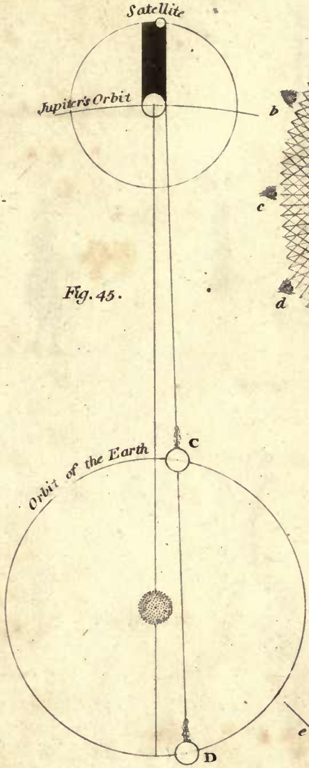

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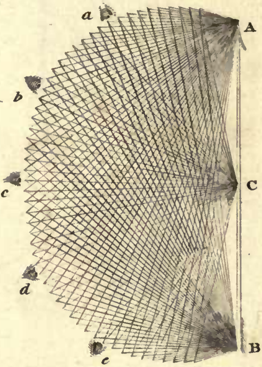

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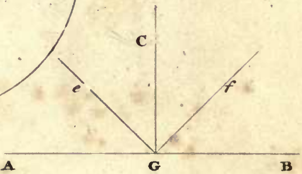

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ELECTRICITY.

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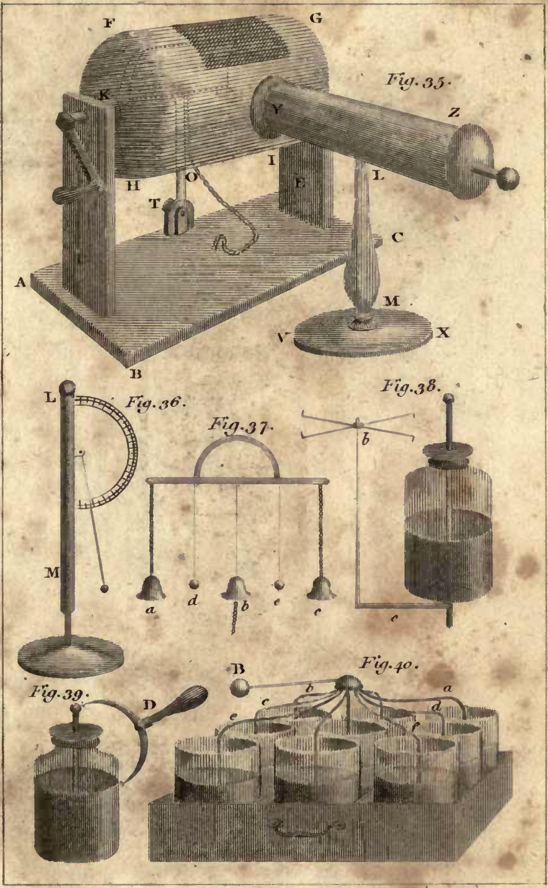

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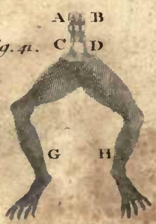

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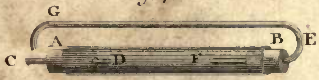

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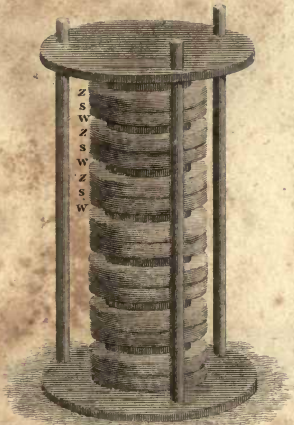

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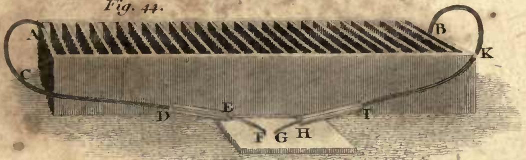

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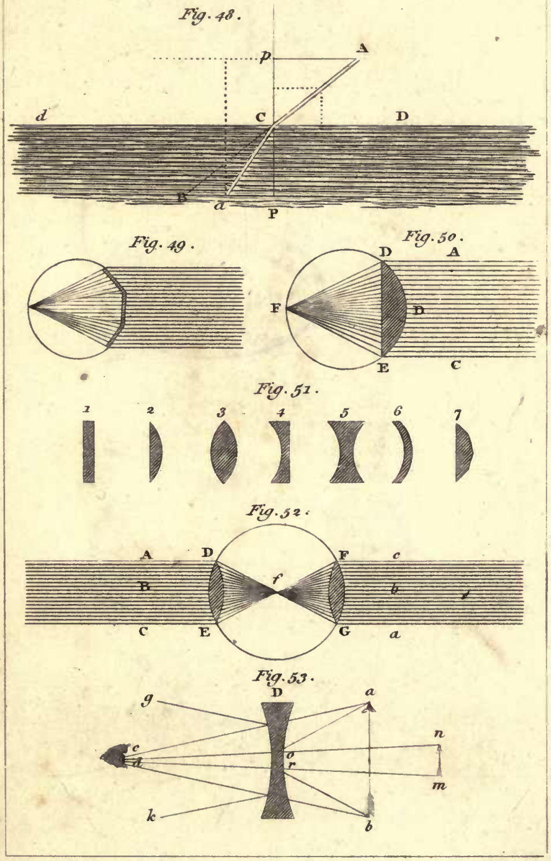

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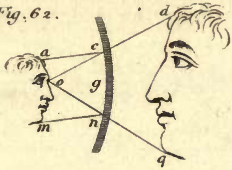

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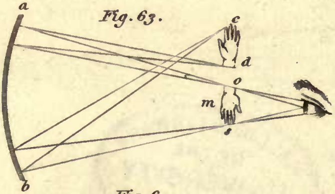

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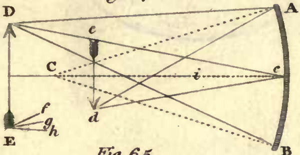

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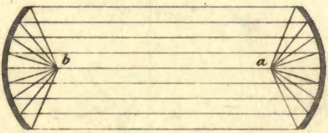

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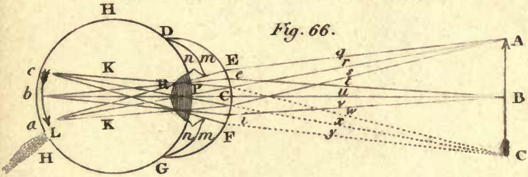

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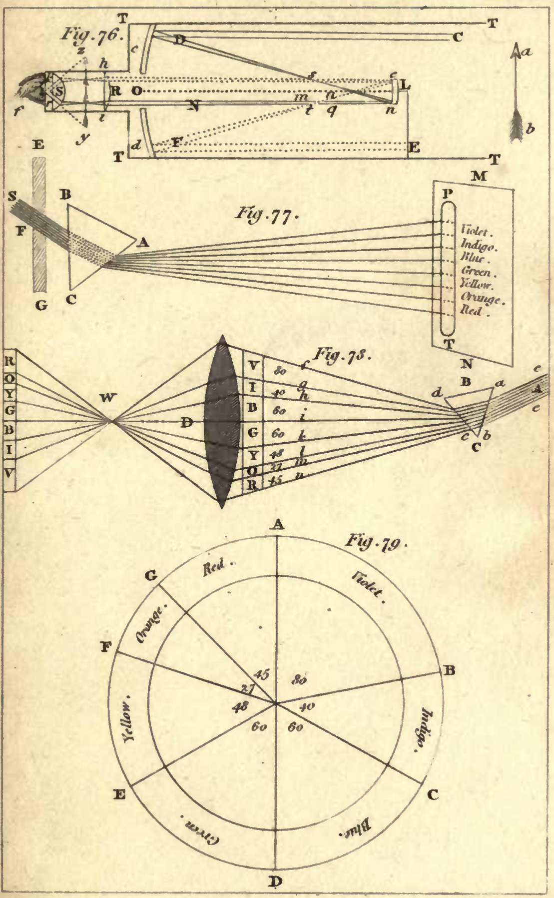

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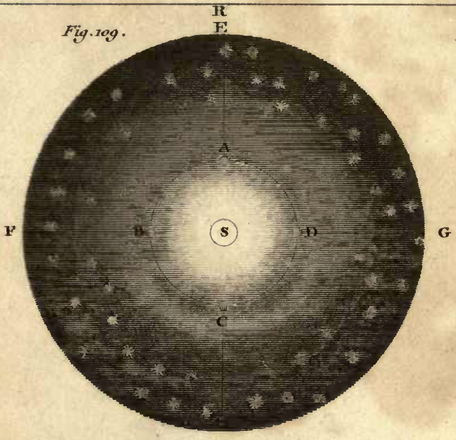

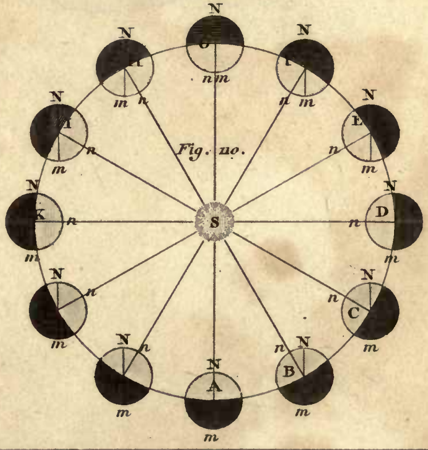

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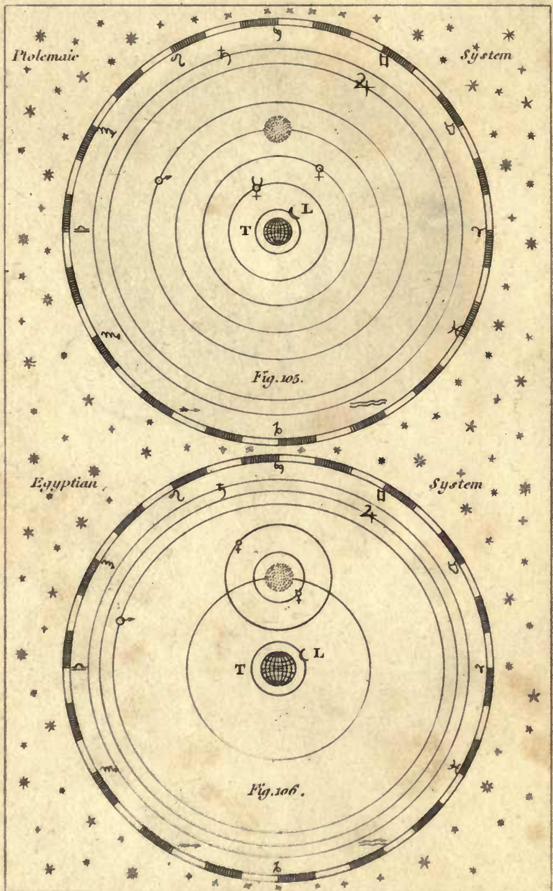

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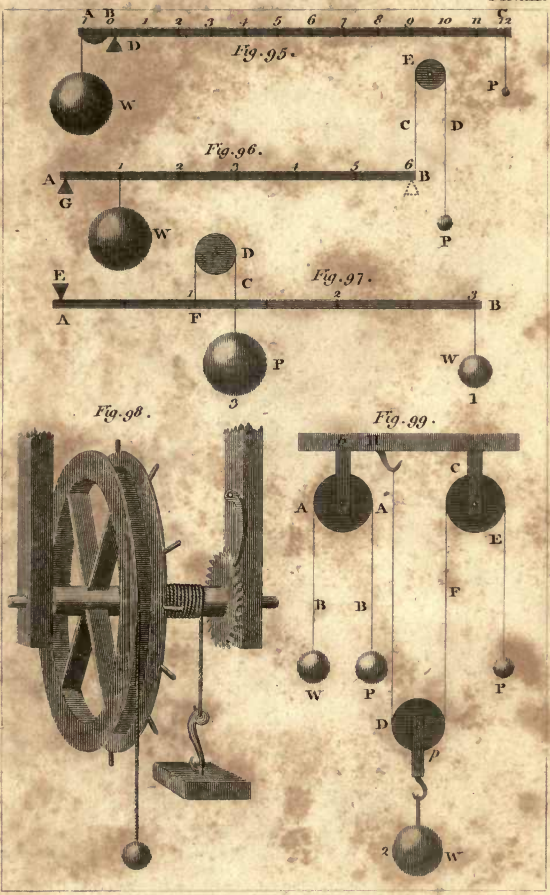

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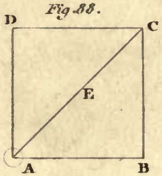

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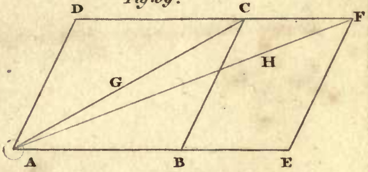

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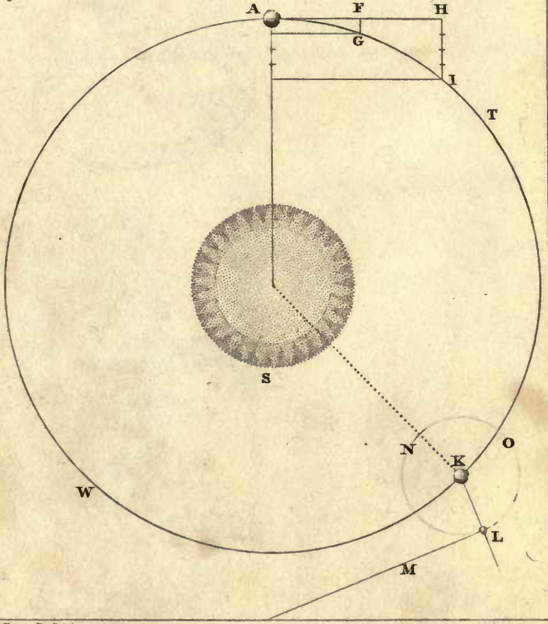

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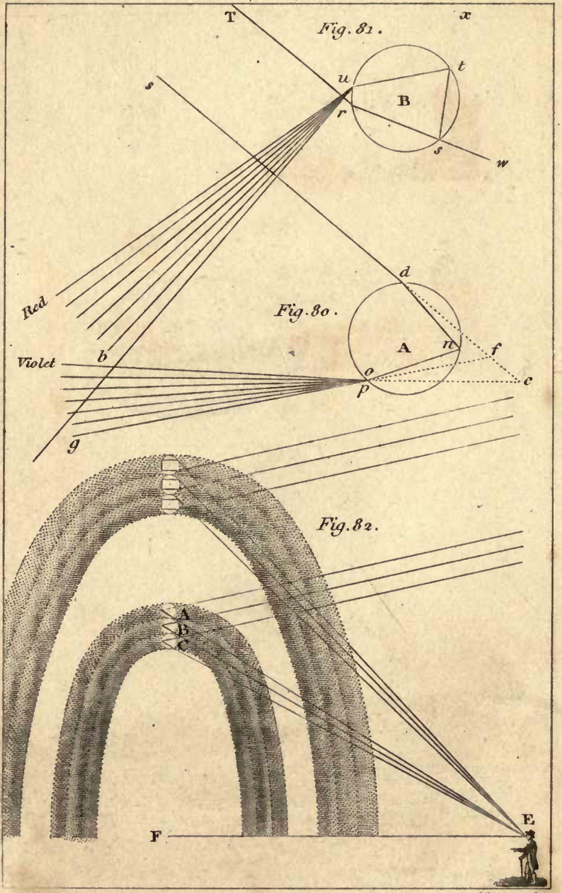

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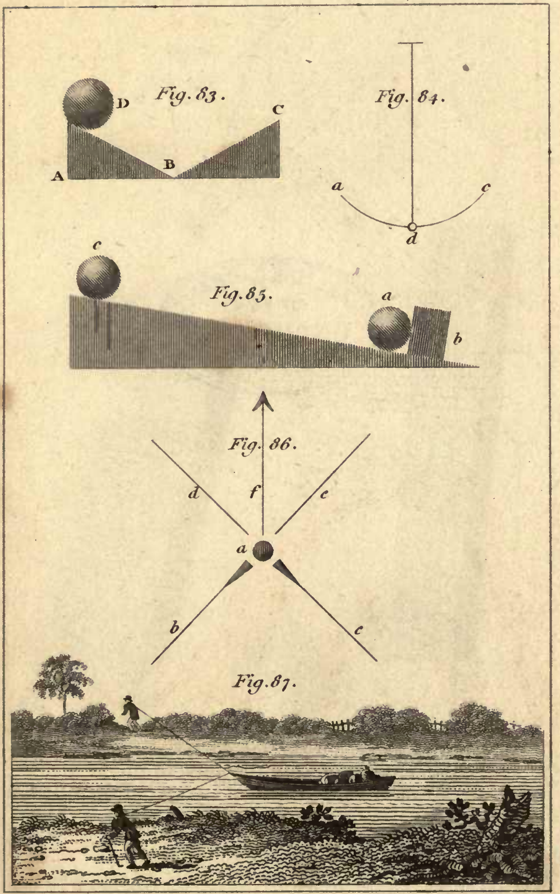

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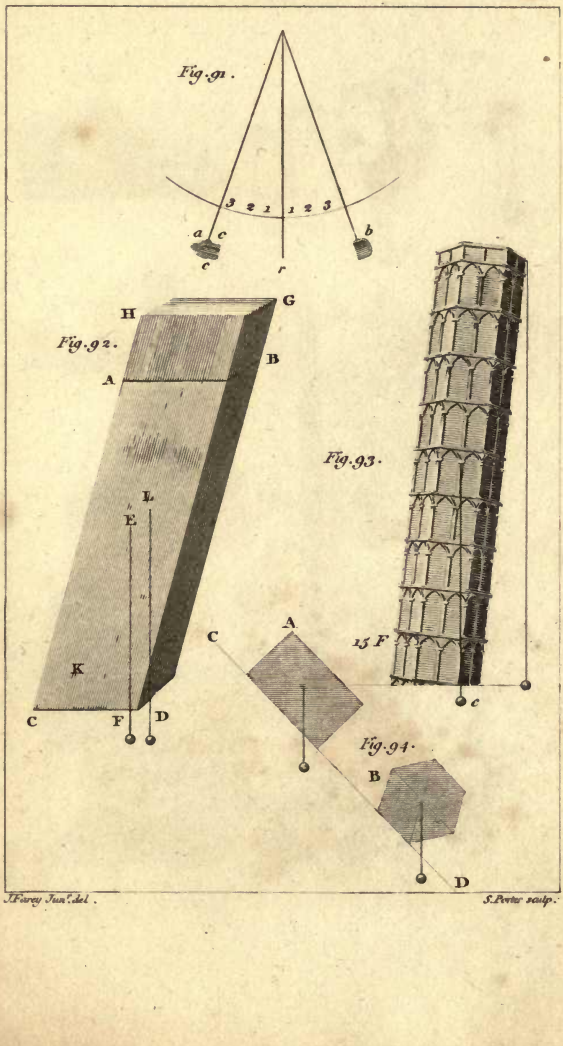

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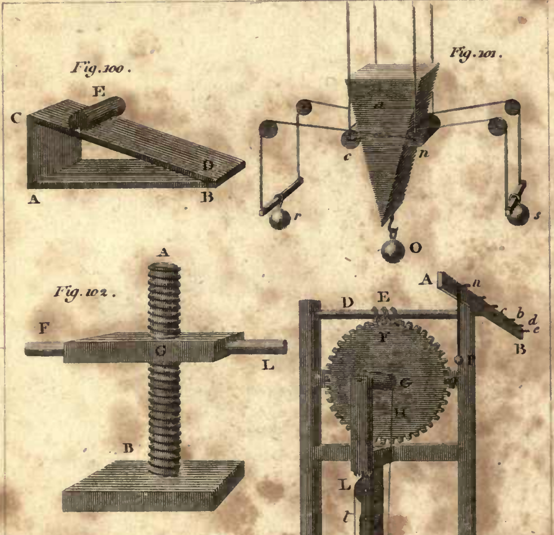

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Copernican System

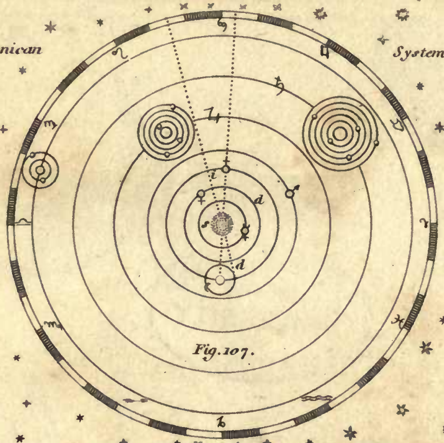

Fig.107.

Tychonic System

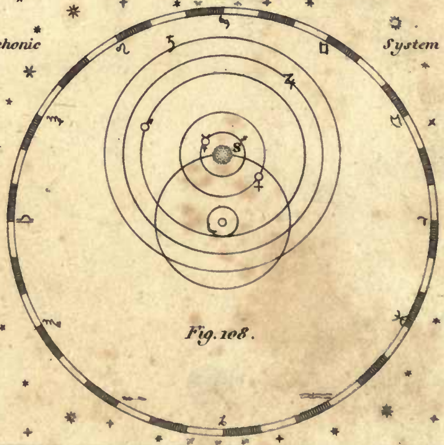

Fig.108.

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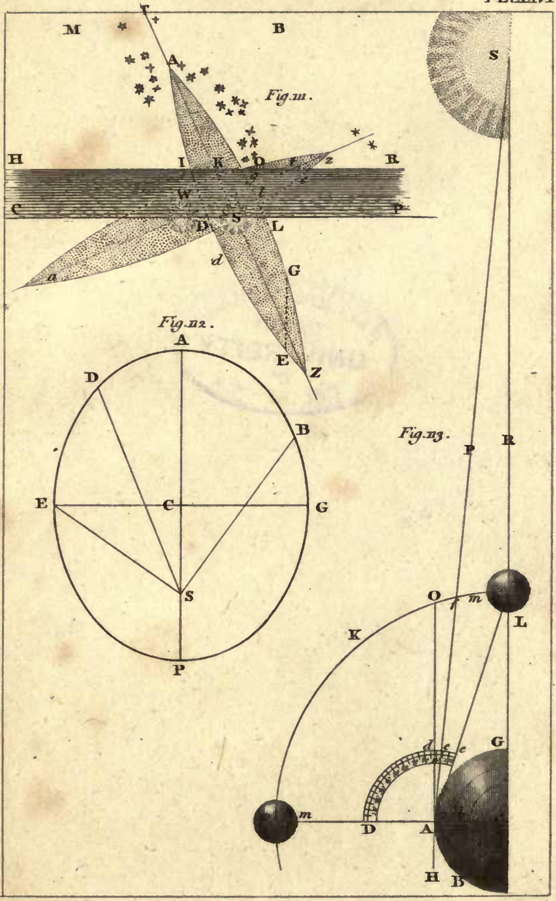

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CHEMISTRY.

PL.V. VOL.II.

Fig. 11.

Fig. 12.

Fig. 13.

Fig. 14.

Fig. 15.

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ASTRONOMY.

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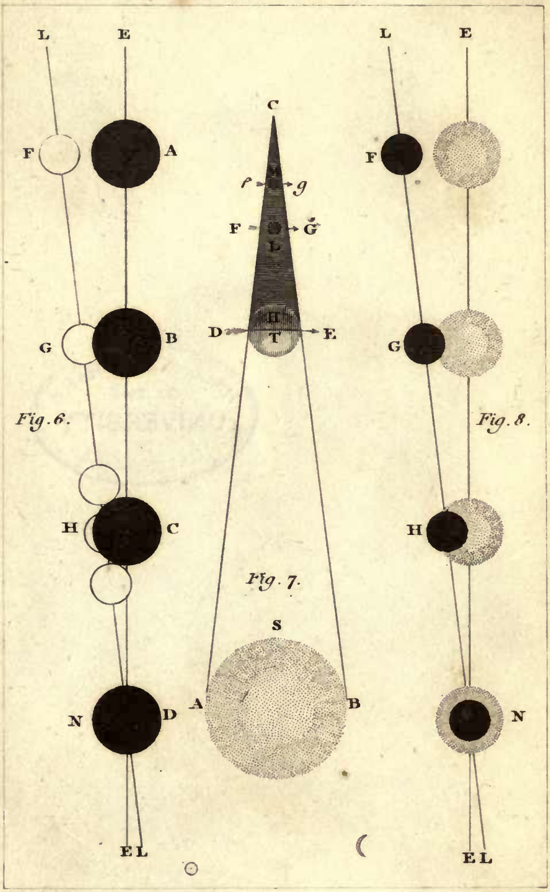

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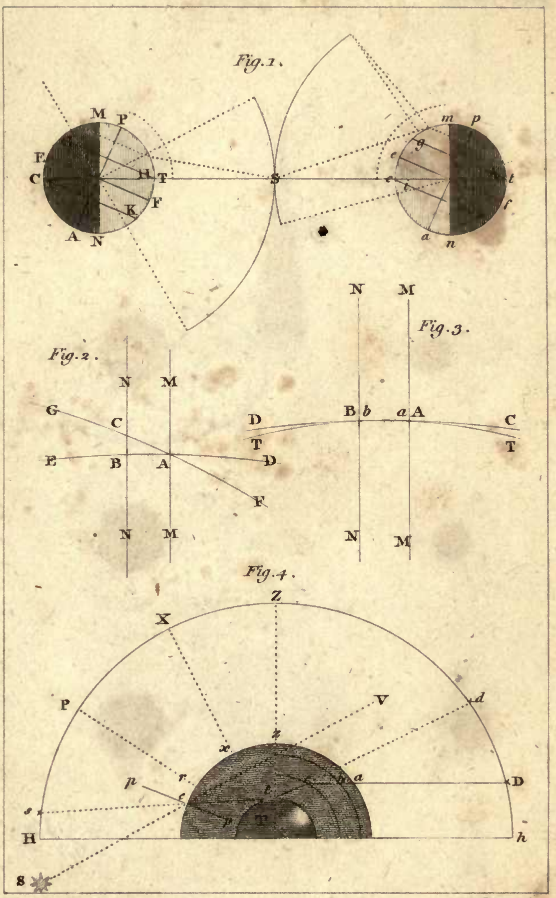

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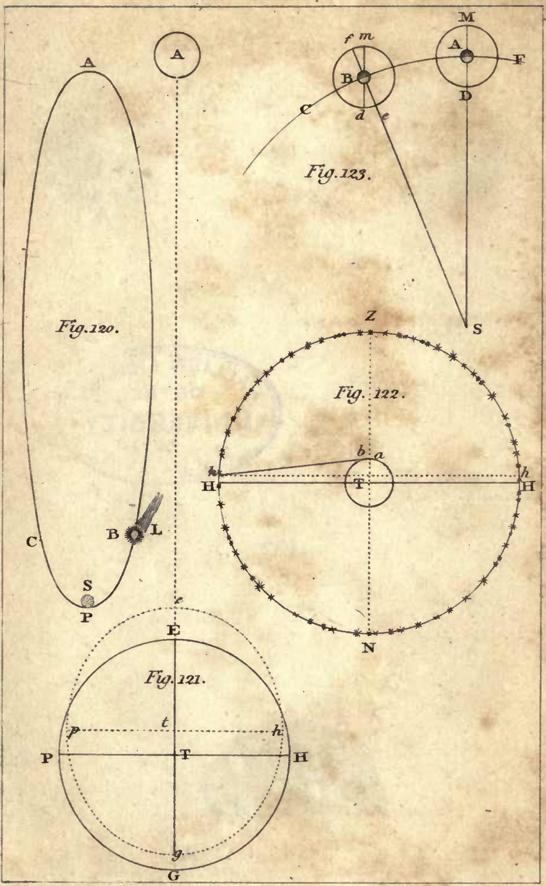

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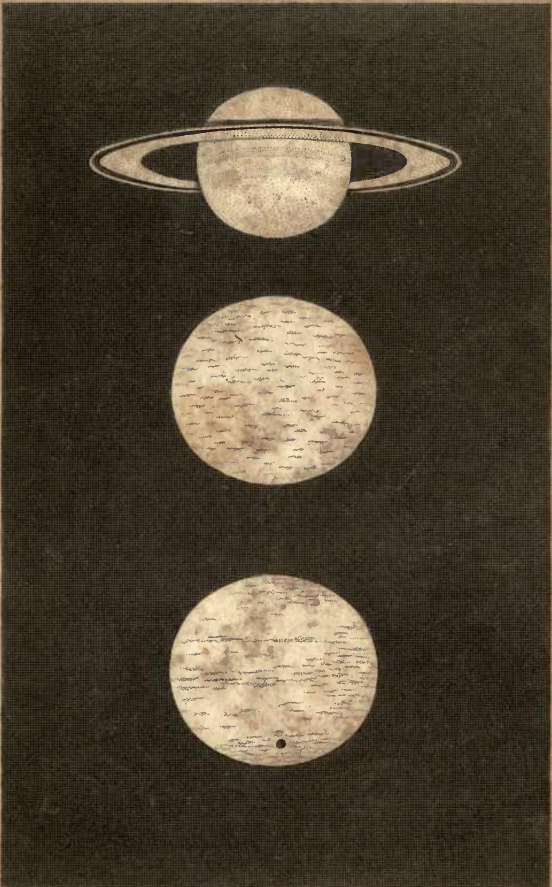

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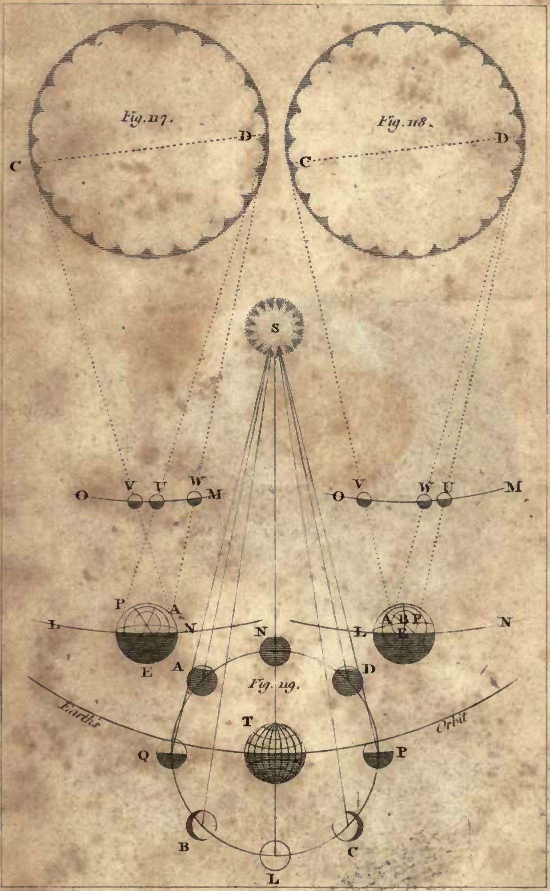
Fig. 116.

S. Porter sculp.

ASTRONOMY:

PL. XXVIII.



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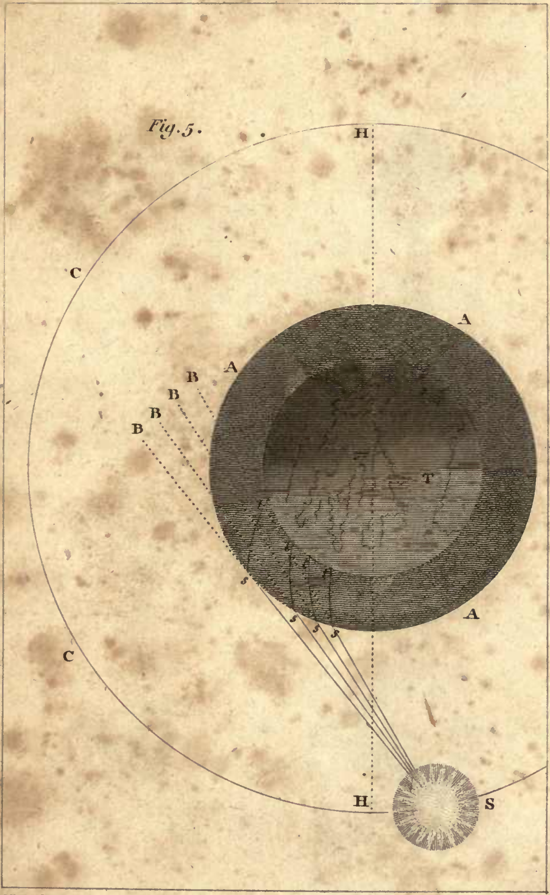

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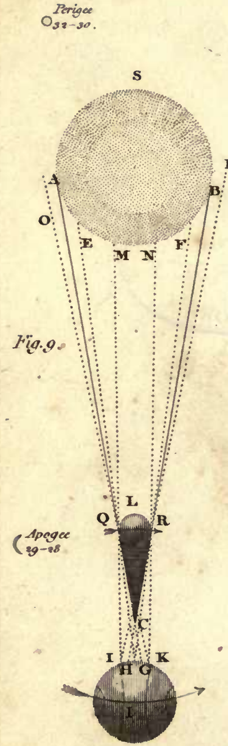

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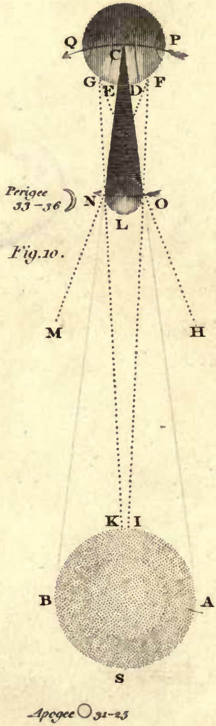

Fig. 10.

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CHEMISTRY.

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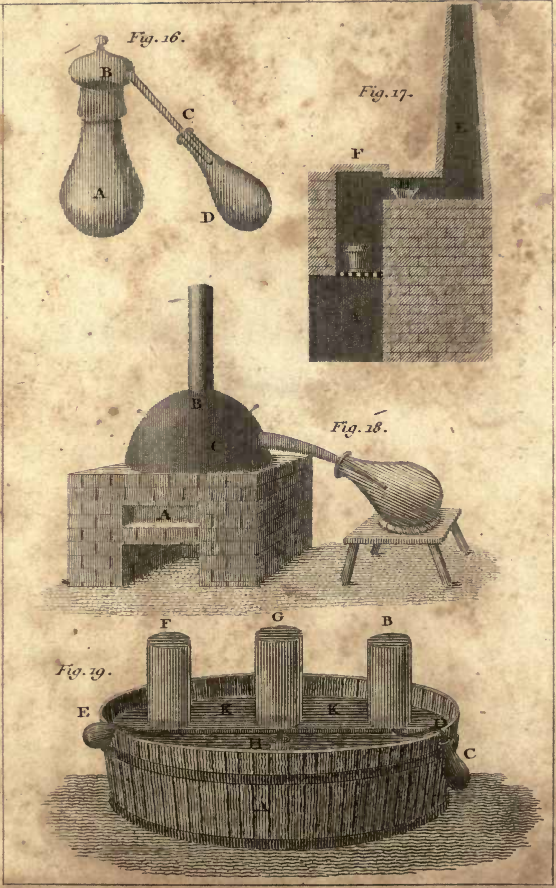

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VOL. I.

EXPERIMENTAL PHILOSOPHY.

CONTENTS.

LECTURES

ON

EXPERIMENTAL PHILOSOPHY, &c.

LECTURE I.

EXPERIMENTAL PHILOSOPHY.

GENERAL OBJECTS AND PRINCIPLES.

You are, I presume, desirous, my young friends, of acquiring knowledge, of satisfying your curiosity, of storing your minds with useful ideas, of fitting yourselves for company and conversation, and of enabling yourselves to proceed gradually in the paths of science, till you arrive at distinction and eminence.

Suffer me to ask you, if you do not feel a strong curiosity to know the nature of all those objects that you see around you; to be informed of the causes of those astonishing changes which you observe every day produce. You see the sun, which apparently rises every morning to give light and heat to the world. You will be surprised to be told, that it is not the sun that moves upon these occasions, but it is the earth on which you stand, that revolves upon an axis, and presents different parts of its surface to the sun at certain hours of the day. Or, when you are told this, do you not feel a wish to know the proofs and the reasons of it; and why the sun appears to move, when in reality it is yourself, or rather the earth on which you stand?—Have patience, and you shall know all this; and it will be as clearly proved to you as any common fact, or as the result of any arithmetical operation.

Again: You throw a stone, or shoot an arrow upwards into the air; Why does it not go forward in the line or direction that you give it? Why does it stop at a certain distance, and then return back to you? What force is it that presses it down to the earth again, instead of its going onwards? On the contrary, Why does flame or smoke always mount upwards, though no force is used to send them in that direction? And why should not the flame of a candle drop towards the floor, when you reverse it, or hold it downwards, instead of turning up, and ascending into the air?

You look into a clear well of water, or on the surface of a looking-glass, and you see your own face and figure, as if it were painted there, and even more correct than the best artist could draw it. Why is this? You are certain there is no such figure, either in the well or behind the looking-glass. You are told this is done by *reflection*. But what is *reflection?* It must be some property in light, which occasions its being thus thrown back to your eyes, and which causes you to see a figure as distinctly as if you looked upon the figure itself. This shall also be explained to you; as well as the reason why when you look upon the ground, at a wainscot, or on a rough unpolished table, you see nothing of the kind.

When you look through some glasses you see things much bigger than they really are, or *magnified;* that is, made larger. When you look through others you see them less than they appear to your eyes, or *diminished.* What is there, then, in the one glass that it should cause things to appear larger than they do to your natural sight: or, in the other, that they should seem so diminished? Yet this too will be explained; and you may, by certain rules, be taught to calculate how much larger or smaller any glass will make an object appear, before you look through it.

You cannot be unacquainted with that tremendous noise, which the ignorance of the antients considered as an indication that their god Jupiter was in a passion. We call it *thunder.* But what is thunder? You have also probably seen fire descend in streams from the clouds, or pass instantaneously from one cloud to another; and after darting first to one side, and then to the other, several times, come to the earth with a zig-zag kind of motion. This is *lightning,* and it proves fatal wherever it strikes: it kills men or cattle; it sometimes levels to the ground the proudest edifices, and sets on fire the loftiest trees or buildings. You have probably never once thought what can be the cause of this thunder and lightning. But will you not be astonished to see it imitated on a smaller scale, the same noise excited, a rapid fire sent forth like that, and producing similar effects?

You see every day the clouds collected over your heads, and passing hither and thither, as directed by the wind. You see them assume different shapes and forms; sometimes gathering into a large thick mass, at others breaking into small divisions. What are the clouds made of, think ye? Whence do they come? Why do they appear and disappear? Why do not they fall down immediately upon the ground, as you see other bodies?

The clouds, you will probably guess, are water, because you see rain occasionally fall from them, and sometimes hail and snow. But how is water supported in the air? Why do the clouds at some times drop only rain, and at others hail or snow? You will say hail and snow fall only in cold weather. But why is snow of that fine flaky consistence like feathers? And why is hail in little round balls? All this may be explained.

You have doubtless observed that beautiful coloured arch in the heavens, which, from its appearance during rain, has been called the *rain-*

bow, and which Almighty God has made the pledge, that he will not overflow the world with another deluge. But do you understand how this appearance is produced? It is, indeed, the action of light upon the drops of the falling rain; but we can show you by what means this appearance, and these vivid colours, are produced; why it assumes the form of a bow; why a second bow is often seen accompanying the first or primary bow. We can measure the arch which it inscribes, and explain the whole of this wonderful spectacle.

It must be well known to some of you from observation, and to most of you by the information of others, that the sea, at certain hours of the day, varying with the age of the moon, approaches, and overflows, to a certain height, the sandy beach by which it is surrounded. This flux and reflux of the ocean, as it is termed, is known by the common name of the TIDE. Antient tradition tells us, that a philosopher put himself to death, because he was unable to find out the cause; but modern philosophy has laid open the whole theory of the tides, and can demonstrate the nature of them upon irrefragable principles.

In some parts of the world there are fountains of boiling water spouting from the earth. In others, the earth itself opens and emits flames and rivers of liquid fire, and throws out rocks and stones of an immense size, with a force and velocity which are imitated in vain by the largest pieces of cannon. Whole countries have been swallowed up, and the proudest cities desolated and destroyed by earthquakes. What is the nature of these surprising operations? From what immediate cause are they produced? On what circumstances do they depend?

You will answer, they are produced by that Almighty Power which first created the universe. It is the hand of God that can alone direct or alter the course of nature. All this is true. Nothing is done, nothing can be done, without the agency, the direction of the Supreme Being.

Yet Providence acts by determinate laws in all the arrangements of nature. It is not by chance, nor by an arbitrary disposal of things, that the operations of nature are effected. By the Divine Wisdom all things are disposed in weight and in measure; they are ordered on certain principles, and effected in certain constant and regular modes.

These modes, in conformity with which the Divine Wisdom acts and governs the material universe, are termed the *laws of nature.* We cannot, it is true, account for every thing; we cannot trace effects to their remotest causes; but yet much is known by long observation, and the discoveries of learned and ingenious men from time to time. They have therefore referred what they call the laws of nature, to a few principles; and these principles, when well understood, will apply to the explanation of a long series of *phænomena*, that is, appearances, from the Greek word *phainomai*, to appear.

It is principally by *experiment* that all the great discoveries of the moderns have been accomplished. This, indeed, forms the grand line of distinction between the antient and the modern philosophy, and this constitutes the sole merit and superiority of the latter. The antients reasoned and conjectured about the nature of things; the moderns have submitted every thing to the direct and positive test of experience: this philosophy has therefore been termed *experimental philosophy*, because all its doctrines and principles are founded upon actual experiment, in opposition to that philosophy which is founded on fancy and conjecture.

It is, I believe, to the old alchemists, or those who were engaged in the whimsical and visionary attempt to discover the philosopher's stone, or a method of converting other substances into gold, that we are ultimately indebted for this excellent philosophy. They engaged in various chemical processes, or experiments, in order to effect this grand discovery; and from their patient and laborious endeavours many useful inventions proceeded, though often foreign from the particular discovery they were in quest of. Our countryman, Roger Bacon, a famous monk, who resided at Oxford in the twelfth century, was one of these; but one of the most rational and sagacious of the whole sect. He was soon convinced of the difficulty of the research in which he was engaged, that of transmuting or changing other metals or substances into gold; but he saw that experiment, and the mode of analysing or dividing bodies or substances into their constituent parts, was the true mode of investigating nature. He therefore ridiculed the idle conjectures and unmeaning jargon of Aristotle and his followers. In the course of his researches he made that wonderful discovery, the composition and use of gunpowder. He had very nearly fallen upon that of air-balloons. He made a number of excellent experiments in chemistry and optics; and you know that his only reward was to be accounted a magician by the ignorant age in which he lived, and even by the unenlightened part of mankind in succeeding times.

To another Englishman, of the same name, the justly celebrated lord Bacon, philosophy is indebted for its next great improvement. He followed the footsteps of his namesake and predecessor; he reduced his principles to a system; and laid it down as a maxim, that it was by experiment alone that any thing in philosophy could with certainty be known. He therefore traced out the way in which future experimentalists might proceed, and afforded a variety of hints, on which they afterwards improved.

The good and the illustrious Boyle, however, may be justly termed the father of modern philosophy. He adopted the Baconian principle of conducting all inquiries by experiment alone. He effected much in the analysing of bodies, and the examination into the principles of which they were composed. He is by many said to have invented that curious and useful instrument, the air-pump; and his experiments on the nature of air have laid the foundation for all the modern doctrines concerning it. His discoveries on light and colours were an excellent introduction to the grand theory of Newton on that subject, and, possibly, served as the basis or foundation of them. In short, there was scarcely a topic of natural philosophy to which he did not bend his attention, and scarcely one which he did not more or less improve: but still the facts educed were insulated.

Such was the state of philosophy when Newton appeared. He reduced, into one grand scheme, all the scattered discoveries of his predecessors. He explained the motions of the heavenly bodies on a principle entirely new, and established that beautiful planetary theory which is now universally received. He developed, with mathematical precision, all the phænomena of light and colours, the nature of vision, and the use of optical glasses and instruments, which last he greatly improved. In short, he gave body and consistency to natural philosophy, and made it, what it never was before, a coherent system of truth, illustrated and proved by experiment.

LECTURE II.

EXPERIMENTAL PHILOSOPHY.

ATTRACTION.

BEFORE we proceed to the higher branches of science, it will be necessary to explain what is usually meant by *attraction*, and the different kinds which have been distinguished by modern philosophers. In the first lecture I called your attention to the effect which follows when you throw a stone, or shoot an arrow upwards into the air. Instead of proceeding according to the direction in which you sent it, you see its force is quickly spent, and it returns to the earth with a velocity increasing as it descends. Now it is easy to conceive that the resistance of the air may stop it in its progress; But why should it return? Why should not the resistance of the air stop or impede it in its return?

The answer you will think very plain—It is its *weight* that brings it back to the earth, you will say, and it falls because it is a heavy body. But what is weight? Or why is it heavy? It is, in truth, the earth which draws or *attracts* the stone or the arrow towards it; this overcomes the force with which you sent it from you at first, and the resistance which the air would otherwise make to its falling. It is the force required to overcome this attraction, which causes a body to be heavy (*gravis*); and hence comes the verbal noun *gravitation*.

To illustrate these matters, drop a little water or any other liquid on a table, and place upon the liquid a piece of loaf sugar, the water or fluid will ascend, or, in vulgar language, be sucked up into the pores of the sugar; that is, the one is attracted by the other. Again, if you take two leaden bullets, and pare a piece off the side of each, and make the surface, where you have taken off the piece, exceedingly smooth, and then press the two balls together, you will find them adhere strongly together; that is, they are mutually *attracted* by each other.

If you take a piece of sealing-wax or amber, with a smooth surface, and rub it pretty quickly upon your coat sleeve till it becomes warm, you will find that if straws, feathers, hairs, or any very light bodies, are brought within the distance of from an inch to half an inch of it, these light bodies will be drawn to the sealing-wax or amber, and will adhere to it. Thus, in philosophical language, they are *attracted* by it.

This last effect is very similar to what you have heard of the magnet or loadstone, or what many of you may have seen performed by the little artificial magnets, which afford a very rational and pretty amusement to young persons. You have seen needles, steel filings, or even knives or keys presented to the magnet, and *at-*

tracted by it. On this circumstance an amusing story in the Arabian Nights Entertainments is founded. A rock of loadstone (adamant it is called by an error of the translator) is supposed to exist in a certain part of the ocean; and when a vessel approaches it, all the iron bolts and nails are attracted by it, and the vessel consequently goes to pieces and is wrecked.

But I can show you a still more surprising (and to most of you, I dare say, new) effect of attraction. I take two phials, which I number 1 and 2, filled each of them with a fluid perfectly colourless; you see they appear like clear water: on mixing them together the mixture becomes perfectly black. I take another phial, No. 3, which contains a colourless fluid also, and I pour it into this black liquor, which again becomes perfectly clear, except a little sediment which remains at bottom. Lastly, I take the phial No. 4, containing also a liquid clear like water, and by adding a little of it, the black colour is restored.

All this may appear to you like magic, but it is nothing more than an effect of attraction. Philosophy keeps no secrets, and I will explain it to you. The colourless liquor in the phial, No. 1, is water in which bruised galls have been steeped or infused; that in No. 2, is a solution of sulphat of iron, the name now given to the *copperas* or *green vitriol* of commerce. In plain terms, it is water in which common copperas or green vitriol is dissolved. The iron which this salt (green vitriol) contains, has a strong attraction for the gall water; and when they are mixed together they unite, and the mixture becomes black; in fact, is made into ink. But when the phial, No. 3, which contains aqua fortis (the nitric acid, as it is called by chemists), is poured in, the iron, which has a stronger attraction for it than for the galls, unites with it, and having left the galls, the liquid is again clear. Again, the phial No. 4, contains potass, formerly called *salt of tartar*, or *of wormwood*. It is the vegetable alkali of chemists. The aqua fortis, or nitric acid, has a stronger attraction for this alkaline matter than it has for the iron; it therefore drops the iron, which again unites with the matter of the galls, and the fluid resumes its black complexion.

You may amuse yourselves with the same experiment in another way. If you write a few words with common ink (which you now know how to make) upon a thick paper, and let them dry, and then take some aqua fortis *diluted* or *weakened* with water, and with a feather drop or rub it upon the letters, the writing will totally disappear. When this is dry, with another feather smear it over with some of the solution of potass or salt of tartar, and the writing will be restored.

These several kinds of attractions which I have now mentioned, philosophers have ranged under five distinct heads. The *first*, that, I mean, of the stone or arrow falling to the ground, they have called the attraction of *gravity*, or gravitation. The second, that of the two leaden balls adhering together, and of the water ascending into the pores of the sugar, they call the *attraction of cohesion*, and also *capillary attraction*. The third is *electrical* attraction, because the sealing-wax, when chafed or warmed by rubbing, is in an electrified or excited state, like the glass cylinder of an electrical machine when rubbed against the cushion, and therefore attracts the hair, feathers, &c. The fourth is the *magnetic* attraction; and the fifth is called *chemical* attraction, or the attraction of combination, because upon it many of the processes and experiments in chemistry depend; and because by this means most of the combinations which we observe in salts, the ores of metals, and other mineral bodies, are effected.

On the two first of these species of attraction only I shall at present enlarge; because it will be necessary to treat of the others when we come to investigate those branches of science to which they properly belong.

First, therefore, of gravitation. It requires no experiment to show the attraction of gravity; for since the earth is in the form of a globe, it is manifest that it must be endued with a power of attraction to retain upon its surface the various bodies which exist there, without their being hurled away into the immensity of space in the course of its rotatory diurnal motion. The earth has therefore been compared to a large magnet, which attracts all smaller bodies towards its centre. This is the true cause of *weight* or *gravity* (which are correlatives). All bodies are drawn towards the earth by the force of its attraction; and this attraction is exerted in proportion to the quantity of solid matter which any body contains. Thus, when two bodies are placed in opposite scales, and we see one preponderate, we say it is heavier than the other; in truth, that it contains a greater quantity of solid matter. For as every particle of matter is attracted by the earth, the greater number of such particles any body contains the more forcibly it will be attracted.

The attraction of matter is universal: so that not only does the earth attract all bodies upon it, or near it; but all such bodies reciprocally attract the earth. Nay, farther, the earth attracts all bodies in the universe, and they, again, all attract the earth. Every particle of matter exerts an attractive energy upon every other particle; and each of the bodies into which particles are grouped attracts every other body. Thus, the sun attracts all the bodies in the planetary system; and they, in their turn, attract the sun and each other. The fixed stars, again, attract each other, and our sun; they also attract, and are attracted by, the several bodies to which they probably form distinct centres. The attractive forces of bodies upon each other, are directly proportional to their quantities of matter, and inversely proportional to the squares of their distances. This is the first grand deduction of the Newtonian philosophy, established upon indubitable principles, and on which all the momentous facts of physical astronomy depend. The tides, the precession of the equinoxes, the irregularities of the moon's motion, the mutual perturbations of the planets, and many other interesting phænomena, all receive a satisfactory explication upon the principle of mutual and universal attraction.

But to proceed: we know by experience that the *weight* or *gravity* of a body or thing is not in proportion to its bulk. A bullet of lead, of the same size as one of wood or of cork, will weigh considerably heavier, and one of gold would be heavier still. It is reasonable, therefore, to suppose that the ball of gold or of lead contains a greater number of solid particles, which are united or pressed closer together than those of the wood or cork; the latter being more porous, and its particles lying less closely compressed or compacted together. One body containing more solid particles within a certain compass, size, bulk, or space, than another, gives origin to the terms *specific gravity* and *density*, which are greater or less in proportion as there are more or fewer constituent particles comprised within a given apparent bulk.

II. The attraction of cohesion is observable in almost every natural object, since in reality it is that which holds their parts together. It has been already made evident in the experiment of the two leaden balls, and the same effect will be proved by pressing together the smooth surfaces of two pieces of looking-glass, particularly if a little moisture is dropped between them to exclude the air more perfectly. The adhesion or tenacity of all bodies is supposed to depend on the degree of this attraction which exists between their particles; and the cohesive power of several solid substances has been ascertained by different courses of experiments, in which it was put to the test what weight a piece of each body of a certain diameter would sustain.

In the following table the numbers denote the pounds avoirdupois, which, at a mean, are just sufficient to tear asunder a rod of each of the bodies, whose base is an inch square.

Metals.

Steel, bar	135,000 lbs.	Tin, cast	4,440 lbs.
Iron, bar	74,500	Bismuth	2,900
Iron, cast	50,100	Zinc	2,600
Silver, cast	41,500	Antimony	1,000
Copper, cast	28,600	Lead, cast	860
Gold, cast	22,000		

Woods.

Locust tree	20,100 lbs.	Teak, Orange	15,000 lbs.
Box	20,000	Alder	13,900
Jujeb	18,500	Elm	13,200
Ash	17,000	Mulberry	12,500

Fir	12,000 lbs.	Walnut	8,130 lbs.
Beech	11,500	Mahogany	8,000
Oak	10,000	Poplar	5,500
Pear,	9,800	Cedar	4,880
Lemon	9,250		

The direct cohesive strength of a body is in the joint ratio of its primitive elasticity, of its toughness, and the magnitude of its section.

Cohesion is also visible even in fluid substances, the particles of which adhere together, though with a less degree of tenacity than solid bodies. "The pearly dew" is a well known phrase in poetical language, and the drops of rain or of dew upon the leaves of plants assume this round or pearly appearance by the attraction which the particles have for one another. In the same manner quicksilver, if divided into the smallest grains, will appear round, like small shot, because the particles attract each other equally in every direction, and thus each particle draws others to it on every side as far as its power extends. For the same reason two small drops of quicksilver, when brought near to each other, will seem to run together and unite.

The attraction of cohesion exists between fluid and solid bodies. Thus a plate of glass or metal (Plate I. fig. 1.) which has been immersed in water or mercury, will retain some drops hanging to it, even when turned upside down, or inverted. Again, if two plates of glass, A.A. (fig. 2.), a little wetted on the surface, and separated on one side by any small interposing body B., about the thickness of a shilling, are immersed in water, the water will rise between them in the curve C. D. E., that is, highest on that side where the plates touch each other, and at a moderate height near the surface of the fluid. The same effect was instanced in the water or liquor rising in the piece of lump sugar; and it may be seen every day, when a piece of blotting-paper is used to suck up a drop of superfluous ink. Another easy experiment will further illustrate the nature of this attraction. Suppose A. B. C. (fig. 3.) two glass plates a little moistened with oil of oranges, and placed upon each other, so as to touch at the end A. B. Let them be kept open at the other end by a small body C. If then a drop of the same oil is introduced at the end which is open, while the plates are kept in a horizontal position, the drop will proceed with an accelerated motion towards the end A. B. If the end A. B. is then a little raised, the drop will be suspended in its course, and, if raised to a considerable height, it will return, but slowly; in which case the attraction of the plates is, in some degree, overpowered by the weight or gravity of the drop. This peculiar kind of attraction has received the name of capillary attraction, from the experiment having been made with small tubes as fine as a horse-hair (*capillus*, Latin), in which the water will rise to a considerable height; and upon the same principle, water or any other fluid will rise in the cavities of a sponge. These experiments will succeed equally in a space which is void of air (such as the vacuum made by an air-pump) as in the open air; so that the effect cannot proceed from any pressure of the atmosphere, but must be caused by attraction alone.

Some bodies, however, in certain circumstances, appear to possess a power the reverse of attraction; and this is called, in philosophical language, *repulsion.* The repulsion of electricity and of magnetism will be evinced when we come to treat of those subjects; and the same feathers, which were at first attracted by the excited or electrified body, will be repelled or driven from it; the magnet will repel at one end the same bodies which it attracts at the other. Upon similar principles, if a small piece of iron is laid on a bason of mercury, it will not sink, but will be supported by it, while the mercury will be depressed on each side; and thus it is that a small needle will swim upon the surface of water.

LECTURE III.

EXPERIMENTAL PHILOSOPHY.

MAGNETISM.

In my last lecture I endeavoured to make you acquainted with the nature of attraction in general. There is, however, scarcely any instance in which the principle of attraction is displayed in a more striking manner than in that of the MAGNET, OR LOADSTONE; so called, as Mr. Adams conjectures, from *load*, the Saxon word for *lead*, that is, the *leading*-stone, from its proving a guide to seamen by means of the compass, or magnetic needle, which always points towards the north.

The loadstone, or natural magnet, is an ore of iron, found more or less in every iron mine. Loadstones are of a dull brownish black colour, and most of them are sufficiently hard to afford sparks like a flint when struck with steel. They differ very much both in form and in weight. There was a very large one in the Leverian Museum, but it did not appear to be very powerful. I observed in my second lecture, that the earth itself has been compared to a large loadstone; and this opinion is countenanced by the immense quantity of iron which is contained within its bowels, or which indeed, more properly speaking, is diffused through all nature. In a part of Virginia there is a magnetic sand, the grains of which exhibit all the properties of larger loadstones, and indeed are loadstones in miniature.

The great and distinguishing property of the magnet is its *attraction* for iron; and this attraction is mutual between them. Thus, if a magnet and a piece of iron are placed each of them on a small piece of wood, in a bason or tub of water, so as to float on the surface, (see Plate II. fig. 4.) the magnet will approach the iron as well as the iron the magnet; and if either of them is held steady, the other will move towards it. Muschenbroek, by a series of experiments, endeavoured to ascertain the degree of force with which a magnet would attract at different distances. He suspended a magnet two inches long, and sixteen drachms in weight, to one of the scales of an accurate balance, and under it he placed a bar of iron, while the weights were put in the opposite scale.

At 6 inches it attracted			3 grains.
5	-	-	$3\frac{1}{2}$
4	-	-	$4\frac{1}{2}$
3	-	-	6
2	-	-	9
1	-	-	18
And in contact			87

From subsequent experiments, it has been proved that the magnetic force diminishes as the square of the distance increases; in *this* respect being analogous to gravity.

Some natural magnets are much more powerful than others; and it is remarked, that the smaller possess the power of attraction in a greater degree, in proportion to their size, than the larger. It indeed frequently happens, that a small loadstone, cut off from a large one, will lift a greater weight of iron than that from which it was cut off. This can only result from the large stone containing a considerable portion of matter not magnetic, which rather impedes the action of the magnetic part than otherwise. Loadstones have been found of not more than twenty or thirty grains in weight, which would lift a piece of iron forty or fifty times heavier than themselves; and we even read of one of only three grains, which lifted a weight of iron of seven hundred and forty-six grains, that is, two hundred and fifty times its own weight.

This property, however, which is possessed by the natural loadstone, it will communicate to any piece of iron by only touching it; and the piece of iron thus converted into a magnet will communicate it to others, and these again to other iron, without losing any part of their magnetic virtue, which seems rather increased than diminished by action. Magnets made by being touched by a loadstone, or by other iron which has been touched by it, are called *artificial magnets*, and are commonly sold in the shops of those who deal in mathematical and philosophical instruments. Soft iron acquires magnetism with more ease than hard iron or steel, but the latter will retain it much longer. A well tempered bar of steel will retain the magnetic virtue for many years without diminution.

The magnet which has the strongest power of attraction does not always communicate it most freely to iron or steel. This circumstance has occasioned a distinction between the different kinds of magnet. Those which communicate most freely and in the greatest degree the magnetic virtue, are called *generous;* those which raise the greatest weight in proportion to their size, are called *vigorous* magnets. The magnetic virtue is not diminished, but is rather increased, by communication. Though however it may be communicated by simply touching the bar of iron or steel, yet it is augmented by repeatedly touching or rubbing it with the magnet: but it must be always rubbed one way only, that is, either from left to right, or from right to left; for if the magnet is drawn backward and forward on the iron the power will be destroyed, for reasons that will be hereafter explained, treating of the poles of the magnet.

The magnetic virtue is found to be the most active at two opposite points of each magnet, which have been termed its poles, from their correspondence with the poles of the earth, as is found by placing the magnet on a small piece of wood floating on water, or in any situation in which it may turn freely, when the magnet will arrange itself nearly in that direction, namely, from north to south. To find the poles of a magnet, place it under a smooth piece of glass, or a piece of white paper, and sift or shake some steel or iron filings on the paper or glass, and you will find them arrange themselves in beautiful curves, as represented in Pl. II. fig. 5. E E. At each pole, however, the filings will take a straight or rectilinear direction, as at A. B. and those which happen to be situated at a small distance from the poles will assume more or less of the curve in proportion to their distance from them. Some natural magnets are found to have more than two poles; in which case they may be considered as two or more magnets united together, and, in fact, have been sometimes separated into so many distinct magnets.

In England we call that the south pole of the magnet which points towards the north, and that is termed the north pole which is directed to the south. The foreign philosophers, on the contrary, name them according to the pole to which they point. That is, the north pole of the magnet is that which is directed to the north or arctic region, and the contrary.

The principle of *repulsion* is also very strikingly exemplified by the magnet; for if the same pole of two magnets is presented one to the other, that is, the north pole of one magnet to the north pole of the other, they will mutually repel or drive away each other: if, on the contrary, the south pole of the one is presented to the north pole of the other, they will be mutually attracted. It is on this account that it is necessary, in making artificial magnets, to draw the magnet, with which they are rubbed or touched, always one way. It is most effectually done also by applying one of the poles of the magnet to the bar or piece of iron which is to be rendered magnetic, and drawing it slowly along several times. It is extraordinary that the end of the bar which is first touched with the magnet will have the contrary property to the end of the magnet with which it is touched or rubbed. If, for instance, the end with which the bar is touched is the north pole of the magnet, the end of the bar to which it is first applied will be a south pole, and the contrary.

It is obvious that the *directive* power of the magnet, or that which causes it, when placed so as that it can freely turn of itself, to take always a position nearly north and south, is the most useful property of the magnet. This is practically applied by means of the mariner's compass, in which a fine needle, index, or piece of steel-wire, formed like the index or hand of a clock or watch, is so balanced as to turn horizontally with great ease on the prop which supports it. The needle or index is fixed in a box; and underneath it the points of the compass, or the different quarters of the horizon; that is, east, west, north, and south, with their intermediate points, are marked on a card. As the magnetic needle always points nearly towards the north, by observing the course or direction of the ship, that is, which way her head is turned, it is easy to know to what point she steers; and by keeping a regular account of the distance she traverses, the seaman can go with considerable exactness from one place to another. Before this great and important invention, seamen usually steered by observing the fixed stars, and particularly the polar or north star. But as this could only be done in fine weather, and when the stars were visible, they frequently lost their way and suffered shipwreck. Indeed few of them dared to sail out of sight of land. But when they had a tolerably certain means of knowing one point of the heavens, it was easy to know the others; and it became, after this invention, neither necessary to observe the stars, nor to be afraid of the open sea, out of sight of the shore. It was by means of the mariner's compass that Columbus was enabled to make the great discovery of the American continent, and by means of it subsequent voyagers have sailed quite round the globe.

Though the position of the magnetic needle, when it comes to rest on a vertical pivot, is, as we have remarked, *nearly* north and south, or coincident with the meridian, yet it is not *exactly* so, nor is it the same at different places, or in the same place at different times. In some parts of the North American continent, the needle now points north and south; at others, it deviates or varies from this position, the *variation* or *declination*, as it is technically called, being in some places westerly, in others easterly. At London, the declination of the needle in the year 1580, was 11° 15′ towards the east. From that time the declination, easterly, gradually diminished until the year 1658, when the position of the horizontal needle at London was precisely north and south. From that period to the present the north end of the needle has deviated more and more from the true north towards the west, until now (in the autumn of 1819), the declination at London is 24° 19′ W. In like manner at Dublin, Edinburgh, Paris, Copenhagen, and other places, where the declination has been long observed, it is found to increase westerly: though in none of those places is the declination the same at it is at London. In all of them, however, it has increased but ittle during the last ten or fifteen years. In 1800, the declination at London was 24° 3′; hence, during the last nineteen years, the declination has not, on the average, varied a minute in a year: and, it is exceedingly probable, that it has nearly, if not quite, attained its greatest western limit in England.

Besides this constant variation in the declination, as referred from year to year, there are minor variations in different parts of the year, and, indeed, in different parts of the day. Mr. Gilpin found by a mean of twelve years, from 1793 to 1805, that the declination appeared to increase, or go westward, from the winter solstice to the vernal equinox 0′.80; to diminish, or go eastward, from the vernal equinox to the summer solstice 1′.43; to increase again, from the summer solstice to the autumnal equinox, 2′.43; and to decrease only 0′.14 from thence to the winter solstice. These minute changes were observed to take place at London: corresponding mutations have been noticed in different parts of the continent of Europe.

With regard to the diurnal variation, Colonel Beaufoy, whose observations have been carried on for some years, at Bushey-heath, near Stanmore, finds the maximum variation to occur at about half an hour past one o'clock in the afternoon. The mean of his observations for May, 1819, give, at 8 h. 37 m. A. M. 24° 32′ 42″ W.
at 1 h. 24 m. P. M. 24° 41′ 22″,
at 7 h. 26 m. P. M. 24° 34′ 10″.

The mean for June, 1819,

give, at 8 h. 40 m. A. M. 24° 31′ 28″ W.
at 1 h. 29 m. P. M. 24° 41′ 41″.
at 7 h. 47 m. P. M. 24° 35′ 09″.

No satisfactory theory of these variations has yet been adduced.

Magnets, while they attract other bodies, appear to be themselves subject to the attraction of the earth; for the magnetic needle, when it is so suspended as to move freely in a vertical plane, generally assumes a position with one of its poles elevated and the other depressed. This, however, varies in different latitudes: near the equator it is in a position almost horizontal; as it approaches the northern regions, the south pole is depressed, or drawn towards the earth; and on the other side of the equator, in the southern latitudes, the north pole is depressed. This is called the *dip* of the needle, and is subject to periodical variations. In 1720, the dip at London was 75° 10′; in 1775, it was 72° 30′; in 1805, 70° 20′; now, in 1819, it is 70° 32′.

Iron may acquire the magnetic virtue by other means than communication with a magnet. 1st. If a bar is kept for a long time in a vertical position, or, still better, in the direction of the dipping needle. Thus old iron bars in windows are often found strongly magnetic. 2d. If iron is heated and suffered to cool quenched in water, holding it in the position of the dipping needle, the same effect is produced. 3d. If it is rubbed hard in the same position by any steel instrument. 4th. A few strokes of a hammer, first at one end of a bar, and then at the other, while held in the position of the dipping needle, will produce the effect. 5th. A shock of electricity passed through the bar will often render it magnetic.

Many entertaining experiments are performed by means of magnetism. In the shops, little swans made of tin, or more properly of iron tinned over, are sold, which, when put to swim in a basin of water, will, when one end or pole of an artificial magnet is presented to them swim after it; and when the other end or pole is turned towards them, they may be chased round the bason. If a small piece of bread is stuck on the end of the magnet which attracts them, an ignorant person will suppose that they are following the bread as if to eat it.

A small fish may also be made in the same manner to swim in a basin of water, and will follow a magnetic hook, or be lifted out of the water by it.

Sometimes an artificial pond is made, about an inch in depth, and seven or eight in diameter, with the hours of the day marked about its edge. One of the magnetic swans is then put to swim in the pond; and if a watch is placed underneath, with a small magnet fixed to the end or point of its hour hand, the swan, guided by the magnet beneath, will then swim to the hour, and show the company the time of day.

But there are not any of the magnetic experiments more interesting or entertaining than that of the divining circles. They are drawn on paper, pasted on the top of a thin box, fig. 6. Pl. II. The index *a*, is fixed on the axle of the toothed wheel *c*, which works into the pinion *d*. On the axle of *d* is another pinion of the same numberof teeth, that puts in motion the wheel *g*, of the same size and number of teeth as the wheel *c*. On the axle of *g* is fixed the bar magnet *qq*, and they turn together. Over this axle (but independent of it) is fixed a point in the top of the box for the loose needle *xx* to turn upon, and which is the centre of the pasted circle F. In the compartments of this circle are written answers to the questions asked in the compartments of the circle G. A circle of strong paper, of the size of F, should cover the pasted circle, and turn easily on the centre; it should have one of the triangular pieces cut out, in order to see the answers. If then the needle *xx* is taken off its point, and a person wishes to ask some of the questions on the carton G, the person must turn the index to the question, and then place the needle on its point, giving it a whirl round, when it will stop over the answer. The open part of the loose circle being turned to that place, will exhibit the answer.

Itinerant jugglers often attract considerable notice by exhibiting a number of these experiments; and there are several very amusing toys constructed upon magnetic principles, and sold in the shops of the makers of mathematical instruments.

After all, however, the theory of magnetism is but imperfectly developed; nor, indeed, have its leading phenomena been very cautiously traced. Very imposing formulæ have been published, especially by continental mathematicians, including, as is pretended, all the phenomena of terres trial magnetism in different latitudes; but when applied to recently ascertained facts, their inaccuracy is at once detected. There is reason to hope that the cloud which has long hung over this department of science will speedily be dispelled.

Hitherto the effect of magnetic attraction has only been stated in very general terms, and no attempt has been made to estimate the quantity of that effect under different circumstances.

Mr. *Barlow*, of the Royal Military Academy, was the first who undertook a regular series of experiments with a view to this determination, and he soon found that there were three distinct conditions to be attended to, *viz.* the position of the needle and compass, with respect to the attracting body, the mass, or rather the surface of that body, and the distance at which the action took place. With respect to position, he discovered that a plane may be conceived to be drawn through the centre of attraction of any mass of iron, inclining from north to south at an angle equal to the complement of the dip, in which plane the iron has no effect on the needle; that is, while the pivot of the compass is found in this plane, the needle will have its true magnetic bearing the same as if no iron were in its vicinity. He also discovered the law of deviation out of that circle, showing it to depend upon the angle which the compass formed with the above plane, and another passing vertically through the north and south points: he likewise found that at different distances, the position being the same, the tangents of the angles of deviation were inversely proportional to the cubes of the distances, and directly proportional to the cubes of the diameter of the attracting ball.

But the most remarkable result obtained in the course of these experiments (with the exception of the discovery of the plane of no attraction above referred to) was, that *the power of an attracting body is independent of the mass of that body*; a simple tin spherical shell of any given dimension, acting equally as powerful as a solid iron ball of the same diameter; which is another striking instance, in addition to many others, of the analogy that subsists between the magnetic and electric attractions. Mr. *Barlow*'s experiments, we understand, are not yet completed: but it is hoped he will soon lay his most interesting results before the world; as they will, doubtless, admit of an important practical application, to the magnetism of iron in ships, and its effect upon the *direction* of the needle in the ship's compass.

LECTURE IV.

EXPERIMENTAL PHILOSOPHY.

HYDROSTATICS.

The word which stands as the title of this lecture, implies simply the science which relates to the weight of water compared with that of other bodies; but the science, as now taught and cultivated, treats not only of the weight and pressure, but of every thing relative to the action and mechanical properties of the dense or incompressible fluids, such as water, &c.

Though water is generally regarded as incompressible, yet it is not entirely so, since it is capable of transmitting sound, which proves that it is elastic, and every elastic body must be compressible. To prove the fact, however, the Florentine academicians filled a globe of gold perfectly full with water, and afterwards closed the orifice by a tight screw. The globe was then put into a press of considerable force; it was a little flattened at the sides by the force of the press, but was proportionably extended in other parts of its surface, so that it was concluded that the water did not occupy less space than before. On pressing it still harder, the water was made to exude through the 'pores of the gold, and adhered to its surface like drops of dew. From this experiment it may be inferred, that if water is indeed capable of compression, it is so only in a very slight degree, since, instead of yielding to the force of pressure, it found its way out through the pores of the metal. The same has been proved more scientifically by subsequent philosophers.

The first principle that may be laid down with respect to the pressure of fluids is, *that the surface of all waters which have a communication whilst they are at rest will be perfectly level.* To explain this more fully, observe the three united tubes (Plate III. fig. 7). It will be seen that if water is poured into the perpendicular tube A, it will run through the horizontal tube C, and rise in the opposite perpendicular tube B to the same height at which it stands in A.

Hence appears the reason why water, conveyed under the earth through conduit-pipes, will always rise to the level of the reservoir whence it is drawn. It is in this manner that the cities of London and Westminster are supplied with water, either from London Bridge water-works or the New River. In the former case, water is raised from the Thames by immense pumps worked by wheels, which are turned by the tide, to the highest part of the town whither water is to be conveyed by pipes; and, in the latter, it is well known that the reservoir of the New River stands on a rising ground near Islington, which is higher than any of the places where the pipes terminate.

It is surprising that the antients should have been totally ignorant of so simple a principle as that of water rising to its level; yet it is to this ignorance that we owe those stupendous works of art, the antient aqueducts, the ruins of which we still behold with admiration. Thus, for instance, in Plate V. fig. 19, an arch or arches would have been built to carry the water from the spring head at the side *a*, across the valley, to supply the house on the other side; whereas a simple pipe of lead, iron, or wood, carried under ground across the valley, will answer every purpose, and supply the house and ponds about it as amply as if an aqueduct had been constructed on the antient plan.

The reason why water thus rises to its level, is because *fluids press equally on all sides:* thus (in fig. 7.) if the tube B were taken away, the water would still press at *b* with equal force as before; and if the tube C were taken away, the water would press against the part *a* as forcibly as it would if it had remained. Thus, if with the thumb we stop the end of the crooked tube *b* (fig. 8.) at *a*, when full of water, the water will press against the thumb with a force proportioned to the height of the water in the tube above *a;* and, if we remove the thumb, it will run over at *a*, and fall in *b* to the level of *a*.

To explain this in a popular way, without the aid of mathematical theory, fluids have been supposed to be constituted of small globules, as represented in fig. 10. If therefore any one of the columns, 1, 2, 3, 4, or 5, be removed, its place will be immediately supplied by a number of small globules, which will roll from the other columns and fill up the vacancy, and consequently the superficies of the whole will presently sink to the same level; as will be found to be the case in a vessel filled with shot, with bullets, or any small round and smooth bodies. On the other hand, supposing these particles to have a very smooth and slippery surface, so as to move with very great ease upon one another, if the vessel which contained them were not full, and any addition were made to the quantity, this addition would displace a number of other particles, which would roll round, and restore the level at the surface. Thus, in fig. 9, we will suppose a perpendicular pressure to be made by the column *ik*, opposite to the point *d*; but as it can proceed no further than that point, because of the bottom of the vessel, the pressure will be directed laterally towards the sides *e f* of the vessel, in such a manner that, if there were any aperture then in the vessel, the fluid would flow out: as that however is not the case, the particles *g* and *h* being restrained by the side of the vessel, those which compose the lateral column force themselves between these particles *g* and *h*, and *h* will be raised towards the surface of the fluid, unless a column equal to *i k* press against it, and keep it in its place. Since therefore the particle *h* would be raised towards the top of the vessel, unless restrained by a pressure quite equal to the column *i k*, it follows, that two columns of water, to be in equilibrium, must be perfectly on a level at their surface.

On this principle we are enabled to account for springs, which are sometimes found on the tops of mountains. They, in fact, come from some waters which are situated upon mountains higher still, and flow through canals or natural pipes, which proceed under ground, perhaps for the distance of miles.

It is upon these facts the maxim is founded, which has led to the hydrostatic paradox, and that is, *that the pressure of fluids is not in proportion to their quantity, but in proportion to their perpendicular height;* and from this the supposed paradox follows, *that a given quantity of water may exert a force two or three hundred times greater or less, according to the manner in which it is employed.*

To make this plain, we will take three vessels of the same height, and the same *base*, though differing materially with respect to their forms, and the quantities they contain, viz. A, B, C, D, fig. 13. E, F, G, H, fig. 11. L, M, N, O, P, Q, fig. 12. Now it may very easily be understood, that the vessel fig. 13, is pressed at the bottom B, C, by the whole mass of water it contains, and that the pressure there must be equal at every part. The vessel fig. 11, however, is of a different shape, and will hold more than three times the quantity of water; yet the pressure at the base is still the same as in the former instance, because the bottom F, G, supports only the column of water I, F, G, K, which is the same as that contained in the vessel fig. 6. All this may be easily comprehended; but the great difficulty lies in understanding how the very small tube in fig. 12. can exert a pressure at the bottom or base of the vessel equal to that in the preceding. Here it will be necessary to remember the maxim that was laid down, That the pressure of fluids is in proportion to their height, and not to their quantity. Thus we may observe the column of water in fig. 12. is equal in height to the columns in fig. 11. and 13; and if we advert to what was said, when speaking of fig. 9, we shall perceive that the small column L, M, P, Q, displaces a quantity of water contained in the lower part of the vessel M, P, N, O, and forces it to rise to the top of the vessel at *s*, for instance, which, if strong enough, will cause a re-action equal to the pressure of a column of water M, P, *r*, *s*. The same will take place at the other side, and at every part of the vessel which is covered, so that in effect the pressure at the bottom N, O, will be the same as if the column of water were equal in size from the bottom N, O, to the top of the tube, as shown by the dotted lines. All this may be proved by experiment, having a false bottom to each of the vessels supported by an iron rod fixed to a balance, as in fig. 13; in which case it will be found that the same weight, at the opposite end of the balance, is necessary to support the bottom in each.

The hydrostatic bellows is a very pleasing machine, constructed upon this principle. It consists of two strong boards, united by leather, almost in the manner of a common bellows, only that for convenience its form is round (see Plate IV. fig. 14.) In this figure *a* is a pipe, which goes into the inside of the bellows, and *u* is a weight laid upon the upper board. If then water is poured into the pipe *a*, the weight will be lifted up; and if the pipe was still taller, a greater weight would be raised. By a very small force exerted in this manner, that is, by water conveyed through a very small perpendicular tube, Dr. Goldsmith relates that he has seen a very strong hogshead burst in pieces, and the water scattered about with incredible force.

To show that this principle in hydrostatics is not without practical utility, it is only necessary to mention, that upon the plan of the hydrostatic bellows a press has been constructed of immense power, see fig. 15, in which *a* is a strong cast iron cylinder, ground smooth on the inner side, and *e* is a piston or moveable plug, fitting very tight within it. *c* is a common forcing pump, in which the water ascends through a valve at its lower end, and is forced through at *o* into the cylinder. This forms a pressure at *m*, by the action of one man working at *s*, which squeezes cotton bags, hay, or other packages, into twenty times less compass than they would otherwise occupy. The effect would be the same if *c*, instead of a pump, were a slender tube, provided it was long in proportion to the pressure which was required.

From all these experiments it is easy to conceive why the banks of ponds, rivers, and canals *blow up*, as it is called. If water can insinuate itself under a bank or dam, even to the thickness of a shilling, the pressure of the water in the canal will force it up. In fig. 18, *a* is the section of a river or canal, and *c* is a drain running under one of its banks. Now it is evident that if the bank *g* is not heavier than the column of water *d e*, that part of the bank must infallibly give way. This effect is prevented in artificial canals, by making the sides very tight with clay heavily rammed down, or by cutting a trench, *n*, from two feet to eighteen inches wide along the bank of the river or canal, and a little deeper, which being filled up with earth or clay well moistened with water, forms a kind of wall when dry, through which the water cannot penetrate.

Another maxim in hydrostatics, of equal importance with the former, is, that *every body lighter than water, or, in other words, which* *swims in it, displaces exactly as much of the water as is equal to its own weight.*

This fact is proved by a very easy experiment. Put a small boat, *a*, (fig. 17.) in one scale, and balance it with *water* in the opposite scale, *b*. If then the boat is put into the basin, fig. 16, exactly filled with water, it will be found that a certain quantity of the water will run over the brim of the basin, which water, on taking out the boat, you will find will be exactly replaced by the water which before balanced the boat in the opposite scale, *b*, fig. 17.

Hence it is plain, that a boat or other vessel sailing upon the water, displaces exactly as much of the fluid as is equal to the vessel and its lading, and, if more weight is added, it will sink deeper in the same proportion, or, in other words, a weight of water equal to the added lading will be displaced; whence a laden ship is said to *draw more water*, that is to sink deeper, than when it is light or unloaded.

Every body, on the other hand, which is heavier than water, or which sinks in it, displaces so much of the water as is equal to the bulk of the body sunk or immersed in the water. Thus it is plain, that if a leaden bullet is dropped into a vessel of water, it will take up just as much room as a small globe of water of equal dimensions. On this principle are computed the tables of specific gravities, by means of what is called the hydrostatic balance; for since every body that sinks displaces a quantity of water exactly equal to its own bulk, it follows, that *every body when immersed in water loses so much of its weight as is equal to the weight of an equal bulk of water.* Thus, if the body, when weighed in air, is two ounces in weight, and an equal bulk of water is one ounce, it will of course lose, when weighed in water, one ounce of its apparent weight. It is by this means that adulterated metals or coins are distinguished from the true ones: thus copper is bulk for bulk heavier than tin, and gold is heavier than copper or brass, which last is a mixture of copper and zinc. If therefore a brass counter is offered for a guinea, if of the same weight, though it may not to the eye appear much larger than a real guinea, yet you may depend upon it that it is so in fact. We will then take a guinea, which we are sure is real gold, and weighing it first in air, and then in water, we shall find it loses about one-nineteenth of its weight in the latter. We then weigh the brass counter in the same way, and find it loses about one-eighth, which we find is much more, and therefore we cannot doubt but the coin is made of base metal. When we look at tables of specific gravities, we see the specific gravity of gold put down at about nineteen one-half, of mercury at about thirteen one-half, lead eleven one-quarter, silver ten one-quarter, copper eight one-half, iron seven one-half, tin seven one-quarter, &c.; that is, gold is nineteen times one-half heavier than its bulk of water, and consequently loses more than one-nineteenth of its weight in that fluid.

This mode of ascertaining the standard value of metals was invented by the famous philosopher Archimedes, who made use of it to detect a fraud in the golden crown of Hiero, king of Syracuse. This king had given a certain weight of gold to be made, by a goldsmith of that place, into a crown; the weight of the crown was exactly the same as the weight of the gold he had received; but Hiero still suspecting an imposition, Archimedes was requested to detect the fraud; and he was led to make the trial in this way, without melting the crown, or destroying the workmanship, from the resistance which he found was made by the water to his own body upon his going into the bath. A quantity of fine gold was therefore brought, and equally balanced in a scale against the crown; but when both came to be weighed in water, it was found that the crown was much lighter; whence not a doubt could remain but that it was made of adulterated metal.

It is upon the same principles that the density of different fluids is put to the test. It might, it is true, be ascertained by weighing them against each other in different scales; but it may be done in a more easy and expeditious manner upon the hydrostatic plan, since the same body that will sink in one fluid will swim in another, and the same body will sink to different depths in different fluids. Thus I have known good housewives in the country try the body of their mead and other liquors, by observing whether an egg will swim in them, which, we know, will sink in common water. The exact relative weight of fluids may be ascertained by suspending from one end of an accurate balance (such as that fig. 17.) either a small globe, or a conical piece of glass. Its weight in water being previously ascertained, which suppose to be two hundred and twelve grains; if it is immersed in a fluid heavier than water, some weights must be added in the opposite scale; as for instance, if it is sea water, then ten grains must be added, which will make the relative weight of sea-water to common water as four hundred and twenty-two to four hundred and twelve. If, on the contrary, it is immersed in brandy, which is less dense, and consequently lighter than water, you will find it necessary to take out of the opposite scale about forty grains, and then the relative weight of brandy to water will be as three hundred and seventy-two to four hundred and twelve, or about one-tenth lighter.

A very convenient instrument is made use of by excisemen, officers of the customs, and all whose business it is to ascertain the density or strength of liquors. It is called an hydrometer, and is nothing more than a small hollow globe of glass or metal with a stem to it, like the handle of a teetotum, but longer, which stem is marked or graduated. The instrument is made so that the ball sinks in water, but not entirely, and therefore a part of the stem is always above the surface. If it is immersed in a fluid lighter than water it will sink, and less of the stem will be above the surface; if in a heavier fluid, it will rise higher, and more of the stem will be visible. This instrument is fully described, and its theory explained more at large in the first vol. of Gregory's Mechanics.

LECTURE V.

EXPERIMENTAL PHILOSOPHY.

HYDRAULICS.

Hydrostatics, we have seen, is that science which relates to the weight and pressure of fluids; the science of hydraulics teaches us what respects the motion of fluids, and the means of raising them by pumps, and conducting them by pipes or aqueducts from one station to another. This branch of science is, also, called *Hydrodynamics.*

It was laid down as a principle, in the preceding lecture, that of all waters which communicate with each other, the surface will be level, or, in common language, that water will rise to its level, or to the same height as its source. The reason of this was not fully assigned then, because it was not necessary; it was observed, that fluids press equally on all sides; but another reason which partly operates to produce the level surface of water is the pressure of another fluid, that is, the air or atmosphere, which, as it bears equally on all points of the earth's surface, must equally press the source from which water is derived and the orifice of the tube or pipe in which it rises, as was evidenced in the three united tubes, which were exhibited as explanatory of this fact.

That a reservoir of water, less than 33 feet in height, will not flow unless exposed to the pressure of the atmosphere, will be plain from filling a cask or other vessel full of this fluid. If the bung is perfectly tight, and there is no aperture above for the air to press upon it and force it out, it is in vain that we shall attempt to draw it off by opening a passage for it below. Hence the use of vent-holes, and vent-pegs in casks: by raising the vent-peg air is admitted, which forces the liquor to flow out at the cock or faucet, whereas if the vent-peg were kept tight no liquor whatever could be obtained. The valencia is a common instrument made of tin, the lower part of which is in the figure of an inverted cone, (see Pl. V. fig. 22.) with an orifice at the bottom *a*, and one at the top *b*. It is used for taking samples of liquors out of the bung-holes of casks. In order to use it, the operator puts it into the bung-hole with both orifices open, and the liquor rises through the orifice at bottom to the top of the instrument; he then puts his thumb on the hole or aperture at top, so as to exclude the air completely, and the liquor will not run out at the bottom till the air is admitted by the thumb being removed, which is done in order to let it flow into the cup or vessel which is to receive it.

Thus it is plain that fluids, circumstanced as above, are put in motion, or caused to flow, by the pressure of the atmosphere; and it will be shown, that whenever that pressure is removed, they will rise above their natural level, and flow where they otherwise would not. The syphon or crane, is a bent tube, of which one leg is longer than the other (fig. 21). With this instrument we want to draw off the fluid contained in the vessel D, which we will suppose immoveable, as a well or a heavy cistern. We know that if the instrument is put into the vessel, without some particular management the fluid can never be made to flow over the bent part B; for the air which presses on the surface of the fluid will also press through the bore of the tube, and prevent its pursuing that course. In order to use it, therefore, we fill the syphon with water or some other fluid, and stopping both ends, immerse the shorter leg in the vessel D. The stoppage being removed, the water will flow out at the leg C by its own gravity, and, by the pressure of the atmosphere on the surface, will continue to flow while there remains any fluid in the vessel. If a vacuum is made in the syphon, by drawing out the air with one's mouth, or in any other way, the same effect will take place.

The syphon fountain is a beautiful example of the effect from the pressure of the atmosphere. In fig. 20, *a* is the long or outer leg of the syphon, which is inserted by a brass or wooden cap in the glass vessel *c*; the inner leg *b* also passes through the cap, and terminates in a spouting pipe of an extremely small bore. To make it act, we must first put it in a position the reverse of what it stands in at present, and through the leg *a* pour in at *d* a quantity of water, which will force the air out of the vessel through the leg *b*. We then stop both orifices with the finger, as in the common syphon, and immerse the leg *b* in the vessel *e* filled with water. The water in the glass will then flow out through the leg *a*; and the glass being vacant of air, the water from the vessel *e* will ascend through the leg *b*, and form a most beautiful jet or fountain within the glass vessel.

The syphon may be disguised in such a manner as to produce many entertaining effects. The cup fig. 23, is called Tantalus's cup, from the celebrated fable of Tantalus, who is represented by the ancients as suffering continual thirst, and though he is in the midst of water, is unable to assuage it—

" E'en in the circling floods refreshment craves,
And pines with thirst amidst a sea of waves;
And when the water to his lips applies,
Back from his lips the treach'rous water flies."

In the cup there is a figure of Tantalus, and if we pour water into it, so that it shall nearly reach to the lips of the image, the water immediately sinks, and is drawn off again. The truth is, there is a syphon concealed within the image; and when the water is poured into the cup, so as nearly to reach the lips, the fluid is then raised above the bend of the syphon, which of course then begins to act, and the water is drawn off by the longer leg in the manner already described.

Sometimes the syphon is concealed in the handle of the cup (see fig. 23.) in such a manner, that when a person raises it to his lips to drink out of it, the fluid which it contains shall be carried over the bend of the syphon, and it will then be drawn off by the longer leg, so that the person shall not only be disappointed of his draught, but will have his clothes well splashed, to the great amusement of the by-standers.

In some parts of the world there are what are called intermittent springs, or wells which seem to ebb and flow like the tides. This we shall perceive is usually caused by a natural syphon. In fig. 24, A is a well of this nature, B is a cavity or reservoir of water under ground, with which it communicates, by means of the pipe or syphon C. It is obvious, that unless the water in the reservoir rises above the height of the bend of the syphon C, the well cannot be filled; but if by considerable rains, or any other cause, the reservoir should become full, then the syphon will begin to act, and the water will run into the well as long as there remains any in the reservoir. It will then cease to receive any more, and the drain from the well will empty it in its turn. At Gravesend there is a pond of this kind, which ebbs while the tide is coming into the adjacent river, fills after the tide has risen to its height, and all the time that it is ebbing in the river. At Lamtown, in Worcestershire, there is also a brook which, in summer, has a stream sufficient to turn a mill, and the greater part of the winter is destitute of water. This probably communicates by a syphon with some cavity in the earth, which is filled by the melting of the snow to a certain height, and after that it will continue to be drawn off by the brook, so as to furnish a stream till the reservoir is entirely emptied.

It is by the pressure of the atmosphere that the common or sucking pump is enabled to act. It is said to have been invented by a mathematician of the name of Ctesebes, about one hundred and twenty years before Christ; but the principle on which it acted was unknown till the 17th century. Mankind, perfectly ignorant that the air had weight, attempted to account for these effects by a maxim not only unfounded, but even destitute of meaning. This was, "that Nature abhorred a vacuum." What they meant by *Nature* is as little to be understood as when the same word is used by those ignorant sciolists who affect to deny the existence of a God. Absurd, however, as this maxim was, it remained uncontradicted till within one hundred and sixty years, when it met with a practical refutation. About that time some workmen were employed by the duke of Florence, to raise water by a common sucking pump to the height of fifty or sixty feet. A pump was accordingly constructed for that purpose; but, after all their efforts, they were unable to raise it above the height of thirty-two feet. It was then found either that Nature had not this horror of a vacuum, or at least, that it was a very limited kind of a horror; for why should Nature have a horror of a vacuum at one height and not at another? The matter was referred to the famous astronomer and philosopher Galileo; but in his time philosophical knowledge was not sufficiently advanced to solve the difficulty.

The difficulty is, however, now explained, through principles furnished by Galileo's pupil Torricelli. We know that a pump is a hollow piece of timber or metal, to the bore of which a piston, bucket, or sucker, is exactly fitted. That the piston has a valve in it made with leather, like the clapper of a bellows. When the piston is pushed down, therefore, the air, or any fluid contained in the pump, will force it open; and when the piston is drawn up, the pressure of the air or water, which has been admitted in that way, will keep the valve down. But to make the matter perfectly clear, let us represent the operation in a glass model. In Pl. VI. fig. 25, is a pump constructed on the plan of a common, or as it is usually called *sucking pump*. Let this pump then, D, C, B, L, be immersed in water at K; in which case you will see the water rise as high as L in the pipe or body of the pump. G is the piston, sucker, or bucket, as it is sometimes called, in which *a* is the valve; and at H is a box made similar to the bucket G with a valve in it *b*, with this difference, that the box H is immovable, and fills the bore of the pump. D is the rod (which is generally of iron) by which the piston is raised. When, therefore, by drawing up the rod B the piston or bucket is raised from B to C, the valve and piston being perfectly or nearly air-tight, it is obvious that a *vacuum* is created, that is, there is a space from B to C, from which the air is drawn out. This, however, is in some measure supplied by the air from below, which enters through the valve *b*, which it opens by its force. It is evident, however, that this air must be exceedingly dilated, by its now occupying so much more space than it did before. The force or spring of the air, within the pump, is so much weakened, that it is not able to resist the pressure of the external air upon the water. The external air, therefore, pressing upon the surface of the water, forces it to ascend through the notched foot of the pump A, perhaps as high as *e* in the body or bore of the pump. By another stroke of the piston G, or by causing it to descend, the upper valve *a* is again opened by the force or spring of the air, and the valve below (*b*) is shut by the same pressure. Thus by the descent of the piston, all the air which was included between the box H and the space C, to which the piston was before raised, will rise above the valve *a* in the piston, and by drawing it up, the valve *a* will again be shut, and a second vacuum created as before, which again will be filled by the air from below, ascending through the lower valve *b*. The spring of the air being thus weakened by this second motion, the pressure of the atmosphere without the pump will cause the water again to ascend within it, we will suppose to F. By the next stroke the air will be almost entirely exhausted, and the water will rise in the body of the pump above the box H, perhaps as high as B. On forcing down the piston or bucket again, the valve *b* in the box H will be shut by the pressure as before, and the valve *a* in the piston G will be opened by the same pressure, and consequently water instead of air will now be raised by the elevation of the piston. When the piston is thus raised, it is evident that a vacuum will again be produced between the box H and the piston C, which will instantaneously be filled up by the water flowing through the valve *b*, as before described. Thus, by the continual working of the pump, the water will be raised by the piston into the wider space, and caused to flow through the spout I. Every time the piston or bucket is raised, the valve *b* is lifted up by the water beneath, and every time the piston or bucket is forced down, the valve *a* rises, and the valve *b* is depressed. For the easiness of working in common pumps, the rod D is fixed to a handle, which acts as a lever, and turns on a pin in the body of the pump.

We have not yet, however, explained the difficulty respecting the pump of the duke of Florence; and you do not yet understand why the water would rise in it no higher than thirty-two feet. We must recollect what was said respecting the cause of the water's rising in the body of the pump. We know it was the pressure of the atmosphere on the surface of the exterior water that forced it to rise. From this circumstance it is evident that the air has weight. But again, as the atmosphere, or that mass of air which surrounds the globe, is only of a limited height (supposed about forty-five miles) and that of gradually diminishing density, it follows that its weight or pressure must be limited also; and it is found that a column of water of thirty-two or thirty-three feet high is, at a medium, equal in weight to a column of air of the same diameter or thickness the whole height of the atmosphere. Consequently the pressure of the atmosphere can never force water through any vacant space higher than about thirty-three feet. By the action of a common pump of four inches bore and thirty feet high, a single man can discharge twenty-seven gallons and a half of water in a minute; if the pump is only ten feet above the surface of the well, the quantity discharged in that time may be eighty-one gallons six pints.

The *forcing pump* is upon a different plan. Here the piston is without a valve, and the water which rises through the valve in the box is forced out by the depression of the solid piston. Thus, in fig. 29, when the piston or plunger *g* is lifted up by the rod D, the water beneath forces up the valve *b* in the box H, and rises into the body or barrel of the pump above H. When the piston *g*, therefore, (which we must observe has no hole or valve in it) is depressed to H, the valve *b* being closed by this action, the water in the barrel of the pump, finding no other vent, is forced into the pipe M M, and so up through the pipe. If there is no occasion for a continued stream of water, the pipe M is continued to any given height, and then the water would be thrown out like a jet-d'eau at every stroke of the piston. But to make a continued stream a further contrivance is necessary.

To this end an air vessel, such as K K, is annexed to the pipe M, and into this air-vessel the water is forced by each stroke of the piston. When therefore the water, by this action continued, gets above the lower end of the pipe GHI, which is fixed air-tight, in the top of the vessel, the air in the upper part is proportionably condensed. The action of the pump being then continued, in proportion as the vessel K K is filled with water, the air above it is compressed, and in return presses on the surface and drives out the water through the pipe at the orifice in its end in a continual stream, and with great force.

It is upon this principle that the famous and truly useful invention of the fire-engine is founded. It consists of two forcing pumps, and a large air vessel which communicates with the pipe. In fig. 27, A B is the body of the engine, in which the water is contained; D and E are two forcing pumps, wrought by the lever FG, moving on the centre *h*. The easiest mode of supplying the engine with water, is that which is usually employed in London in cases of fire, when a leather pipe communicates with the orifice of one of the pipes which supplies the city with water. When this cannot be done, the water is poured by buckets into the vessel AB, and being strained through the wire grating N, is, by the pressure of the atmosphere, raised (as before described in treating of the forcing pump) through the valves at the lower end of the barrels D and E, when either of the forcers ascend, and at their descent it will be forced through the other valves alternately, into the air vessel C: the air, therefore, in this vessel being very strongly compressed, by its spring it will force the water up through the metal pipe within the air vessel; the part Q of which being flexible, its end may be directed to any part of the building where the flames predominate.

By the means of forcing pumps water may be raised to any height above the level of a stream or spring, provided the machinery is sufficiently powerful to work them. The London Bridge water-works, which supply the city of London with water, consist of a certain number of forcing pumps, which are worked by large wheels turned by the tide. There is also a beautiful engine of this kind at the duke of Marlborough's at Blenheim.

The most powerful forcing pumps, however, are wrought by steam engines, for steam is one of the strongest powers in nature. The steam engine consists of a large cylinder or barrel, in which is nicely fitted a solid piston, like that of a forcing pump. The steam is supplied from a large boiler close by, and is admitted into the cylinder by an orifice, which can be occasionally shut. The force of the steam lifts the piston, to the top of which is affixed a long lever to work a forcing pump, or for any other purpose; and when the piston is lifted a certain height, it opens a small valve in the bottom of the cylinder, through which a small quantity of cold water being admitted the steam is condensed, and thus a vacuum being created, the piston again descends, and is again lifted up by the force of the steam. For a detailed description of this invaluable engine, however, our readers must consult the Encyclopædiæ or Pantologia, and our best treatises on Mechanics.

LECTURE VI.

EXPERIMENTAL PHILOSOPHY.

OF PNEUMATICS.

THE air we breathe is an heterogeneous mixture, that is, a matter composed of different substances, and not of particles of perfectly the same nature. This is one of the secrets which the wonderful discoveries of modern chemistry have revealed to us. According to this system, caloric, or the matter of fire, is the basis of all fluidity, and therefore air may be considered as consisting of very minute particles, which swim, or are suspended in a mass of that very subtile and active fluid. The properties of caloric are not, however, perceptible in this mixture; for on account of the attraction which subsists between those particles of which air is composed, and those of caloric, the latter is rendered *latent*, as Dr. Black expresses it, or, in other words, inactive. The matter of atmospheric air is therefore composed of caloric as its basis, and some other matters. Or the other matters may be considered as dissolved and floating in the mass of fire, like salt, or gum, or any other substance in water. The nature of these matters will be explained in the chemical lectures, and would be improper at present, since it is of the general properties of air of which I am now to treat, or rather of its mechanical and not its chemical properties.

Fluids are divided into two classes; the incompressible, and the elastic. That branch of science which is called hydrostatics treats of all the known qualities of the former, and that of pneumatics embraces all which respects the general properties of the elastic fluids. The elastic fluids are again divided into two classes, those which are condensible, such as vapour, which is easily condensed by cold; and the permanently elastic fluids, of which there are many, such as oxygen air or *gas* (the word *gas* being an old German term signifying spirit *), nitrogen or azotic gas, or phlogisticated air, as it was first called, carbonic acid gas or fixable air, hydrogen gas or inflammable air (that which is used to inflate balloons), nitrous gas, hepatic gas, &c. But of their general or mechanical properties the common air will serve to give a perfect idea.

The properties of air of which the science of pneumatics particularly treats, are its weight, pressure, and elasticity or spring.

That air, like all other bodies, is possessed of weight or gravity many obvious facts will serve to convince us; and, in truth, it may be reduced to the simplest of all experiments, for air may be ac-

* Whence our word ghost.

tually weighed. If, for instance, a bottle which holds a wine quart is emptied of its air, either by the action of the air pump, or by filling it with quicksilver, and emptying the quicksilver out, taking care that, in corking it, no air is suffered to enter, it will be found to be sixteen grains lighter than it was before it was emptied of its air. A quart of air, therefore, weighs just sixteen grains; a quart of water weighs fourteen thousand six hundred and twenty-one *, which, divided by sixteen, gives a result in round numbers of nine hundred and fourteen; so that water at a medium is nine hundred and fourteen times heavier than air.

This, however, is only to be understood of air near the surface of the earth; for, in fact, as air is a body possessed of gravity, that which is nearest the earth sustains a greater pressure, and is consequently more dense or compact; and it is rarer or more thin and light in the higher regions of the atmosphere, being less pressed with the weight of air which is above. The atmosphere, I observed in my last lecture, is that mass of air which surrounds the globe, and which is generally computed to be about forty-five miles in height. If altitudes in the air are taken in arithmetical proportion, the rarity of the air will be in geometrical proportion; and therefore supposing that the atmosphere extended to the height

* A quart of water is generally calculated at two pounds, but it is in fact something less.

of five hundred miles, it has been computed that one cubic inch, such as the air we breathe, would be so much rarefied at that height, that it might fill a hollow sphere equal in dimensions to the orbit of Saturn.

We need not, however, have recourse to calculations to prove a fact so generally understood. All persons who have visited the tops of high mountains know by experience that the air is thinner or rarer at those altitudes than below. As they ascend their breathing becomes quicker, the atmosphere is clearer, neither clouds nor vapours can rise to such heights; and it is common in these situations to see the lightning below pass from one cloud to another, while all above is clear and serene. Ulloa, who went to take the measure of a degree upon the earth's surface, informs us, that while he stood on the top of one of the Andes in Peru, the clouds, which were gathered below the mountain's brow, seemed like a tempestuous ocean, all dashing and foaming, with lightnings breaking through the waves, and sometimes two or three suns were reflected from its bosom. "In the mean time he enjoyed a cloudless sky, and left the war of the elements to the unphilosophical mortals on the plain below him."

The reason of all this must be evident. The clouds are vapour, that is, water rarefied by heat; vapour is lighter than air near the surface of the earth, but in the higher regions the air is thinner and lighter than these vapours, and consequently they can only ascend to a limited height. What Ulloa observed on the Andes, has been confirmed by the adventurers in balloons, and particularly by Mr. Baldwin, who ascended from Chester in the year 1785. The earth was entirely hid from his view by the immense mass of vapours: he compares them to a sea of cotton, tufting here and there by the action of the air, and soon after the whole became an extended floor of white cloud.

To prove the weight and pressure of the atmosphere I shall mention an easy experiment, which the student may make himself, without any philosophical apparatus. If we nearly fill a common saucer with water, and then take a tea-cup, and burn in it a piece of paper; while the paper is yet burning, turn down the cup, paper and all into the saucer, we shall soon see that the pressure of the air upon the water contained in the saucer will force it up into the cup. To understand the nature of this experiment it is necessary to anticipate in some degree what will be the subject of future lectures. Heat, caloric, or fire, is now known to be a real substance; when, therefore, the paper is burned in the teacup, the air is driven out by another fluid (viz. caloric) taking its place. Caloric, however, penetrates all substances; and therefore when the flame is extinguished, it is dissipated through the pores of the cup, leaving almost a perfect vacuum, to fill which the water is pressed up, as before described. It would rise, if there were no impediment, to the height of thirty-two feet, because, as I explained in my last lecture, a column of the atmosphere is at a medium equal in weight to a column of water of that height.

The weight of the air, or rather of the atmosphere, is, however, exactly determined by the following experiment.

Take a glass tube about three feet long, open at one end; fill it with quicksilver, putting the finger upon the open end, turn that end downward, and immerse it into a small vessel of quicksilver, without admitting any air: then take away the finger, and the quicksilver will remain suspended in the tube twenty-nine inches and a half above its surface in the vessel; sometimes more, and at other times less, as the weight of the air is varied by winds, vapours, and other causes. That the quicksilver is kept up in the tube by the pressure of the atmosphere upon that in the bason, is evident; for, if the bason and tube are put under a glass, and the air is then taken out of the glass, all the quicksilver in the tube will fall down into the bason; and if the air is admitted again, the quicksilver will rise to the same height as before. The air's pressure therefore on the surface of the earth, is equal to the weight of twenty-nine inches and a half depth of quicksilver all over the earth's surface, at a mean rate.

A square column of quicksilver, twenty-nine inches and a half high, and one inch thick, weighs just fifteen pounds, which is equal to the pressure of air upon every square inch of the earth's surface; and one hundred and forty-four times as much, or two thousand one hundred and sixty pounds upon every square foot; because a square foot contains one hundred and forty-four square inches. At this rate a middle-sized man, whose surface may be about fourteen square feet, sustains a pressure of thirty thousand two hundred and forty pounds, when the air is of a mean gravity; a pressure which would be insupportable, and even fatal to us, were it not equal on every part, and counterbalanced by the spring of the air within us, which is diffused through the whole body, and re-acts with an equal force against the outward pressure.

Now, since the earth's surface contains, in round numbers, 200,000,000 square miles, and every square mile 27,878,400 square feet, there must be 5,575,680,000,000,000 square feet on the earth's surface; which, multiplied by 2,160 pounds, (the pressure on each square foot) gives 12,043,468,800,000,000,000 pounds for the pressure or weight of the whole atmosphere.

The above experiment on the quicksilver, which is called the Torricellian experiment, after its inventor Torricelli, who made it about the year 1645, is the foundation of that instrument which is called the *barometer*, so useful in foretelling changes of the weather. In the common barometer the quicksilver in the ball below is left open to the pressure of the atmosphere, which, according as it increases in weight or density, presses on the surface of the quicksilver, and forces it into the vacuum in the glass above. When the air is dense or heavy it supports the clouds and vapours; when it is rarefied and thin it is unable to support them, and they fall in the form of mists, rain, hail, or snow. When, therefore, the quicksilver rises in the glass, we say it is a sign of fair weather, when it falls it prognosticates foul.

That the air is *elastic* is easily seen from various experiments, particularly when it is confined in a bladder or any flexible substance, we then find it may be compressed by force into a narrower compass, and that it will expand again when that force is removed. But of all instruments for showing the elasticity as well as all the other properties of the air, the air-pump is the most complete. It was invented nearly simultaneously by our illustrious countryman, Mr. *Boyle*, and a celebrated German, *Otto Guericke*.

Whoever is acquainted with the construction of a common water-pump, can have no difficulty in comprehending the nature and action of the air-pump; the principle is exactly the same, and we may therefore, without further preface, refer immediately to the Plate VII. fig. 28, to explain its operation.

Having put a wet leather on the plate L L of the air-pump, place the glass receiver M upon the leather, so that the hole *i* in the plate may be within the glass. Then, turning the handle F backward and forward, the air will be pumped out of the receiver; which will then be held down to the plate by the pressure of the external air or atmosphere. For, as the handle F is turned backward, it raises the piston *d* in the barrel B K, by means of the wheel E and rack D: and, as the piston is leathered so tight as to fit the barrel exactly, no air can get between the piston and barrel; and therefore all the air above *d* in the barrel is lifted up towards B, and a vacuum is made in the barrel from *b* to *d*, upon which, part of the air in the receiver M, by its spring, rushes through the hole *i*, in the brass plate L L, along the pipe G, which communicates with both barrels by the hollow trunk I H K, and pushing up the valve *b*, enters into the vacant place *b d* of the barrel B K. For wherever the resistance or pressure is taken off, the air will run to that place, if it can find a passage. Then, if the handle F is turned forward, the piston *d* will be depressed in the barrel; and, as the air which had got into the barrel cannot be pushed back through the valve *b*, it will ascend through a hole in the piston, and escape through a valve at *d*, and be hindered by that valve from returning into the barrel, when the piston is again raised. At the next raising of the piston, a vacuum is again made, in the same manner as before, between *b* and *d*; upon which more of the air that was left in the receiver M gets out thence by its spring, and runs into the barrel B K, through the valve *b*. The same thing is to be understood with regard to the other barrel A I; and as the handle F is turned backward and forward, it alternately raises and depresses the pistons in their barrels, always raising one while it depresses the other. A vacuum being made in each barrel when its piston is raised, the particles of air in the receiver M push out one another by their spring or elasticity, through the hole *i*, and pipe G, into the barrels; until at last the air in the receiver becomes so much dilated, and its spring so far weakened, that it can no longer get through the valves, and then no more can be taken out. Hence there is no such thing as making a perfect vacuum in the receiver; for the quantity of air taken out at any one stroke will always be as the density of it in the receiver: and therefore it is impossible to exhaust it entirely, because, supposing the receiver and barrels of equal capacity, there will be always as much left as was taken out at the last turn of the handle.

There is a cock *k* below the barrels, which being turned, lets the air into the receiver again; and then the receiver becomes loose, and may be taken off the plate.

There is also a glass tube *m n* (fig. 29.) open at both ends, and about thirty-four inches long; the upper end communicating with a hole in the pump-plate, and the lower end immersed in quicksilver at *n* in the vessel N. To this tube is fitted a wooden ruler *m m*, called the *gage*, which is divided into inches and parts of an inch, from the bottom at *n* (where it is even with the surface of the quicksilver), and continued up to the top, a little below, to thirty or thirty-one inches.

As the air is pumped out of the receiver M, it is likewise pumped out of the glass tube *m n*, because that tube opens into the receiver through the pump-plate; and as the tube is gradually emptied of air, the quicksilver in the vessel N is forced up into the tube as in a barometer, by the pressure of the atmosphere. And if the receiver could be perfectly exhausted of air, the quicksilver would stand as high in the tube as it does at that time in the barometer: for it is supported by the same power or weight of the atmosphere in both.

The quantity of air exhausted out of the receiver on each turn of the handle, is always proportionable to the ascent of the quicksilver on that turn; and the quantity of air remaining in the receiver, is proportionable to the defect of the height of the quicksilver in the gage, from what it is at that time in the barometer.

By means of the air-pump all the mechanical properties of air are, as before observed, most completely ascertained. Thus the weight and pressure are clearly proved by a very easy and obvious experiment. If we take a vessel of a long or cylindrical shape, (fig. 30.) which is open at the top, and place it on the pump, where the receiver stands in fig. 28, then press it on the top with the hand so as to exclude the external air, we shall find, as the vessel begins to be exhausted of air, a considerable pressure on the back of the hand; and if the operation is continued, that pressure will even become painful, and we shall perceive it impossible to remove the hand. This evinces that the weight of that column of air which is above must be considerable, and that the calculation above stated, of the weight which a man's body usually bears, is not overrated. If, instead of the hand, a piece of bladder is tied over the open top of the vessel, we shall see the bladder gradually sunk in like a jelly-bag, and at length burst with considerable force by the pressure of the external air; a flat piece of thin glass, placed in the same situation, will be broken in pieces. Why then is the glass receiver, which, we see, is placed on the pump in fig. 1, not broken? The reason of this is, first, the shape of the glass, which is globular or arched at top, and this is found, by long experience, to be the best form for supporting a weight; secondly, these receivers are generally made of thick glass, and with particular care, so as to sustain a greater pressure than that of fifteen pounds on a square inch without any danger of breaking. A beautiful experiment to evince the pressure of the air, is this. Let a metallic cup be provided, in whose bottom shall be fixed a cylinder of thorn, or some other wood, about three inches long; and let this cup and attached cylinder be placed at the top of the receiver of the air-pump, so as to exclude all external air. Then let quicksilver be poured into this cup, and let a glass to receive it be placed within the receiver. Then, as the rarefaction of the interior air proceeds, the quicksilver will be forced, by the external pressure, through the pores of the wood, and will be seen to descend in a beautiful shower.

Various facts in nature are explained by understanding the pressure and force of the air. The word *suction* is founded on a vulgar error, for, in fact, there is no such thing. In all cases where suction is supposed, a vacuum or void is created, and the pressure of the atmosphere forces the fluid to fill up this void. Thus when children suck at the breast, the mouth and lips of the child act as an air-pump. The child swallows the air in his mouth, while he holds the nipple fast in his lips, so that none can come in that way. A vacuum, of course, is created, and the external air pressing on the breasts of the mother, squeezes the milk into the infant's mouth. The action of cupping glasses is explained on the same principle. The air is driven out of the cupping glass by means of heat, (as in the experiment with the tea-cup,) that part of the body where the glass is applied has therefore no pressure of air upon it, and the fluids of the body are driven to that part where there is least resistance.

By the air-pump we are also convinced more clearly of the elasticity and compressibility of the air. Take a bladder from which the air is almost totally exhausted, and which appears quite flaccid and compressed, tie the neck of it tight as it was when full, and put it in an air-pump. As the air is exhausted we shall see the bladder gradually inflate, till, at length, it will be puffed out to the full size it was before we had expelled the air. Mr. Boyle relates that, by means of the air-pump, he had rarefied common air so as to make it fill nearly fourteen thousand times the space it did before.

A similar effect would take place with a bladder, by carrying it to the higher regions of the atmosphere, where, as before explained, the air is thinner and lighter, and consequently its pressure less. If a bladder half full is carried up to the top of a high mountain, it will gradually dilate to its former size.

If, instead of a bladder almost empty, a full-blown bladder, or a thin glass bubble filled with air, and closely stopped, is put into the air-pump, as soon as the air is exhausted, the bladder or the bubble will burst in pieces.

The air is also capable of being rarefied by heat. If a bladder, half blown and tightly tied at the neck, is held to the fire, we shall find that it will dilate to nearly its full size; and if either a full-blown bladder or a thin glass bubble filled with air is held close to a strong fire, it will burst.

That air is a compressible fluid must be evident, when we consider that it is elastic; and it must be further evident from what was said in the last lecture on the use of the air vessel annexed to the forcing pump and common fire engine. There is, however, a beautiful experiment expressive of the effects from compressed air, which, with the aid of the plate, I shall endeavour to describe. It is a kind of artificial fountain, which is made to send out a stream or jet of water by means similar to those employed in the fire engine, that is, by a body of compressed air forcing the water contained below it through a small pipe, and out of the jet or orifice of the pipe. In Plate VIII. fig. 21, A B C D, is a copper vessel, which may be made of any convenient form; within the vessel is a small pipe or tube N O open at bottom, and with what is called a stop cock *, such as R, at the upper end to keep in the air when it is necessary. To make the fountain play, we first fill it about two-thirds full, with water, then screw in the pipe, which must be made air-tight by oiled leather. The air contained between the surface

* A stop cock is exactly like the common cocks used in beer barrels, &c.—When turned one way there is an orifice through the stopple, which then admits the air, or any fluid; when turned the other way it is solid, and stops the passage.

of the water and the top of the vessel is then of the same density with that of the atmosphere. We then take the condensing syringe, fig. 32, and screw it above the stop cock, and force a quantity of air into the vessel, which, as it cannot return, forces its way through the water into the upper part of the fountain, where it remains in a condensed state; while the air in the fountain or vessel is condensing, we turn the stop cock R to prevent the escape of the water. We then screw on a jet or pipe with a small aperture at top, and when we turn the stop cock again, the condensed air above, by its expansion, forces the water through the pipe, and out at the jet, in a beautiful fountain.

The condensing syringe, fig. 32, is made like a common squirt or syringe; but it has a valve at bottom, which, instead of opening inwards as the valve of a pump, opens outwards at R. Near the top of the syringe there is a small hole P. When, therefore, the condensing syringe is screwed on the vessel, if we draw up the piston (which is solid, as in a squirt, and not with a valve, like the piston of a pump) there will be a vacuum left between that and the valve, till we draw up the piston as far as the little hole P, near the top. When it gets past the hole, the external air will rush in and fill up the vacuum; when we push the piston down again, by which action the valve below is opened, and the air forced into the vessel—the valve shuts, and restrains the air from returning.

Air, it is said, may be thus compressed into fifty thousand times less compass than its natural bulk, provided the apparatus is strong enough. On this principle of condensed air is constructed the air-gun, a very dangerous and destructive instrument. It was formerly a very complex machine, from having the chamber for containing the condensed air within the body or rather the butt end of the gun. That which is now in use was invented by the late ingenious Benj. Martin: see fig. 33. It is in shape exactly like a common gun. Just below the lock, a copper ball A, fig. 34, screws on, which is charged or filled with condensed air by a condensing syringe, exactly as we charge the brass fountain, only that the ball contains no water; the ball has a stop cock *a*, which is turned or shut when it is not on the gun: the bullet is rammed in as we charge a musket, but must fit the barrel very exactly. By drawing the trigger, a small valve is opened at the bottom of the barrel, and it is so contrived as to let out only one charge of condensed air at each pull of the trigger; the bullet is discharged with a force sufficient to kill an animal at the distance of sixty or seventy yards. The copper ball contains about ten charges. There are generally two of these to each gun, and that which is not immediately in use may be carried in the pocket.

In the next lecture we shall treat of the atmospherical phænomena.

LECTURE VII.

EXPERIMENTAL PHILOSOPHY.

THE PHÆNOMENA OF THE ATMOSPHERE.

THE word phænomenon, the plural of which stands at the head of this lecture, and which we shall frequently have occasion to use, means simply an *appearance*. It is derived from the Greek verb PHAINOMAI, which signifies to appear; but it is generally used to imply any striking or remarkable appearance. The atmosphere was before explained to mean that mass of air which surrounds the earth. Various conjectures have been made with respect to the height of the atmosphere; and, as we know to a certainty the relative weight of a column of the atmosphere by the height to which its pressure will raise water or mercury in an empty tube, so different calculations have been founded on these data, to ascertain its extent as well as its density at different heights. If the air of our atmosphere were indeed every where of an uniform density, the problem would be very easily solved. We should, in that case, have nothing more to do, than to find out the proportion between the height of a short pillar of air, and a small pillar of water of equal weight; and having compared the proportion the heights of these bear to each other in the small, the same proportion will be certain to hold in the great, between a pillar of water thirty-two feet high, and a pillar of air that reaches to the top of the atmosphere, the height of which we wish to know. Thus, for instance, we find a certain weight of water reaches one inch high, and a similar weight of air reaches seventy-two feet high: this then is the proportion two such pillars bear to each other in the small. Now, if one inch of water is equal to seventy-two feet of air, to how much air will thirty-two feet of water be equal? By the common rule of proportion we readily find, that thirty-two feet, or three hundred and eighty-four inches of water, will be equal to three hundred and thirty-one thousand seven hundred and seventy-six inches, which makes something more than five miles, which would be the height of the atmosphere, were it homogeneous, or its density every where the same as at the earth's surface, where seventy-two feet of air were equal to one inch of water.

But this is not really the case; for the air's density is not every where the same, but decreases as the pressure upon it decreases; so that the air becomes lighter and lighter the higher we ascend; and in the upper regions of the atmosphere, where the pressure is scarcely any thing at all, the air, dilating in proportion, must be expanded to a surprising degree; and therefore the height of the atmosphere must be much greater than has appeared by the last calculation, in which its density was supposed to be every where as great as at the surface of the earth. In order, therefore, to determine the height of the atmosphere more exactly, geometricians have endeavoured to determine the density of the air at different distances from the earth.—The following sketch will give an idea of the method which some have taken to determine this density.

If we suppose a pillar of air to reach from the top of the atmosphere down to the earth's surface; and imagine it marked like a standard by inches, from the top to the bottom; and still further suppose, that each inch of air, if not at all compressed, would weigh one grain. The topmost inch, then, weighs one grain, as it suffers no compressure whatsoever; the second inch is pressed by the topmost with a weight of one grain, and this added to its own natural weight or density of one grain, now makes its density, which is equivalent to the pressure, two grains. The third inch is pressed down by the weight of the two inches above it, whose weights united make three grains; and these added to its natural weight, give it a density of four grains. The fourth inch is pressed by the united weight of the three above it, which together make seven grains; and this added to its natural weight gives it a density of eight grains. The fifth inch, being pressed by all the former fifteen, and its own weight added, gives it a density of sixteen grains; and so on, descending downwards to the bottom. The first inch has a density of one, the second inch a density of two, the third inch a density of four, the fourth inch of eight, the fifth of sixteen, and so on. Thus the inches of air increase in density as they descend from the top, at the rate of one, two, four, eight, sixteen, thirty-two, sixty-four, &c. which is called a geometrical progression. Or if we reverse this, and begin at the bottom, we may say, that the density of each of these inches becomes less upwards in a geometrical progression. If, instead of inches, we suppose the parts into which this pillar of air is divided to be extremely small, like those of air, the rule will hold equally good in both. So that we may generally assert, that the density of the air, from the surface of the earth, decreases in a geometrical proportion.

This being understood, should we now desire to know the density of the air at any certain height, we have only first to find out how much the density of the air is diminished to a certain standard height, and thence proceed to tell how much it will be diminished at the greatest heights that can be imagined. At small heights the diminution of its density is by fractional or broken numbers. We will suppose at once that at the height of five miles, or a Dutch league, the air is twice less dense than at the surface of the earth: at two leagues high, it must be four times thinner and less dense, and at three leagues eight times thinner and lighter, and so on. Instead of Dutch leagues, suppose we took a German league of seven miles, and that it was four times less dense at the height of the first German league, then it would decrease in the same proportion, and be four times less dense than the first at the second league, that is, sixteen times; and four times less dense than the second at the third league, that is, sixty-four times; and four times less dense than the third at the fourth league, that is, two hundred and fifty-six times less dense than at the surface. In short, whatever decrease it received in the first step, it will continue to have the same proportion in the second, third, and so on, and this, as was observed, is called geometrical progression.

Upon the same principle it was attempted to calculate the height of the atmosphere. By carrying a barometer to the top of a high mountain, the density of the air at two or three different stations was easily ascertained.—But, alas! so feeble are human efforts in endeavouring to comprehend and measure the works of the Creator, that this theory was soon demolished. It was found that the barometrical observations by no means corresponded with the density which, by other experiments, the air ought to have had; and it was therefore suspected that the upper parts of the atmosphere were not subject to the same laws or the same proportions as those which were nearer the surface of the earth; or that, changes of temperature might operate with other causes to change the law. Another ingenious method was subsequently devised.

Astronomers know, to the greatest exactness, the place of the heavens in which the sun is at any one moment of time: they know, for instance, the moment in which it will set, and also the precise time in which it is about to rise. However, upon awaiting his appearance any morning, they always see the light of the sun before its body, and the sun itself appears some minutes sooner above the mountain top, than it ought to do from this calculation. Twilight is seen long before the sun appears, and that at a time when it is eighteen degrees lower than the apparent horizon, or verge of the sky. There is then, in this case, something which deceives our sight; for we cannot suppose the sun to be so irregular in his motions as to vary every morning: for this would disturb the regularity of nature. The deception actually exists in the atmosphere. By looking through this dense, transparent substance, every celestial object that lies beyond it is seemingly raised up, in a way similar to the appearance of a piece of money in a bason filled with water. Hence it is plain, that if the atmosphere were away, the sun's light would not be brought to view so long in the morning before the sun itself actually appears. The sun, without the atmosphere, would appear one entire blaze of light the instant it rose, and leave us in total darkness the moment of its setting. The length of the twilight, therefore, at a given time, is in proportion to the height of the atmosphere: or let us invert this, and say, that the height of the atmosphere is in some proportion to the length of the twilight. This consideration led to an investigation (to which we shall recur when we treat of astronomy) from which it has been inferred that at the height of 45 miles, the atmosphere has sufficient density to bend the rays of light. At greater altitudes, the density is not sufficient to occasion any perceptible effects.

The density of the air, however, depends not merely on the pressure it sustains, but on other circumstances; so that it varies even at the same height in different parts, and in the same place at different times, as is seen by the mercury in the barometer rising to different heights, according to the state of the weather. Heat in particular was mentioned as a very powerful cause in rarefying the air. From this circumstance arises one of the most striking and formidable of the atmospherical phænomena—the WIND. Wind is nothing but a strong current or stream of air. Whenever the air is heated by the sun, or by any other means, it will be rarefied, and less able to resist the pressure of the adjacent air, which will consequently rush in "to restore the equilibrium," to speak in the technical language of philosophy, or, in plain terms, to reduce the rarefied part to an uniform density with the other. This current of air is sensibly felt near the door of a glass-house, or wherever there is a large fire. A current of air is also to be perceived rushing through the key-hole, or any chink or crevice, into a heated room. This may serve to give a general idea of the causes of winds.

This principle we consequently find realised on a great scale, in what are called the *trade winds*, which blow constantly from east to west near the equator. When the sun shines intensely upon any part of the earth, it is plain that, by the immense accession of heat, the air must be greatly rarefied. The cold air will therefore rush from the adjacent parts to that where there is little resistance, and consequently cause a stream or current of air, in other words, a wind, towards that quarter. The sun rises in the east, and sets in the west, consequently the air will be heated gradually from east to west, and the wind will blow in that direction. Near the equator, therefore, where the surface of the earth is heated in succession from east to west, there will be a constant wind from the east, but on the north side of the line it will incline a little to the north, and on the south side a little to the south, for an obvious reason, because it is colder towards each pole, and therefore the mass of cool air will be principally drawn from these quarters.

The same cause will explain, in a popular way, the land and sea breezes in the tropical climates. In islands, and small tracts of land which run into the sea in those regions, it will generally be found that, during the day, there is a current of air towards the sea, and at evening the current sets in from the sea to the land. The reason of this is, that water is always of a more even temperature, that is, of a more equal heat, than land. During the day, therefore, the land becomes considerably heated, and the air is rarefied; the consequence is, that in the afternoon a breeze sets in from the sea, which is less heated. On the contrary, during the course of the night the land loses its heat, while that of the sea continues more nearly the same. Towards morning, therefore, a breeze regularly proceeds from the land towards the ocean, where the air is warmer, and consequently more rarefied, than on shore.

The *monsoons* are periodical winds which blow between the tropics, and which, though the theory of them is rather more complicated, originate in the same cause. They depend, indeed, upon large tracts of territory being heated during the warm season, by which the general course of the trade winds is partially interrupted. Thus, when the sun approaches the tropic of Cancer, the soil of Persia, Bengal, China, and the adjoining countries, is so much more heated than the sea towards the southward of these countries, that instead of the usual trade wind, the current of air proceeds at that season from the south to the north, contrary to what it would if no land was there. But as the high mountains in Africa, during all the year, are extremely cold, the low countries in India to the eastward of it become hotter than Africa during the summer, and the air is naturally drawn thence to the eastward. From the same cause the trade wind in the Indian ocean blows, from April to October, in a north-east direction, contrary to the general course of the trade wind in the open sea in the same latitude; but when the sun retires behind the tropic of Capricorn, these northern parts become cooler, and the general trade wind assumes its natural direction. In the northern tropic the monsoons depend upon similar causes.

In our climate the winds are more variable, because the rarefactions which take place in the air are here more partial, more frequent and sudden, than in the tropical regions. I have sufficiently explained, that whatever dilates or rarefies the air in any part must produce a wind or current of air towards that part. Among the most powerful causes of winds, therefore, we must account the electricity of the atmosphere, which (as will be explained hereafter) is the cause of thunder and lightning. A thunder storm, therefore, is commonly either preceded or followed by a smart gale of wind. The rays of the sun are also sometimes partially interrupted by clouds or mists in particular places, consequently the earth will be more strongly heated in one part than another, in which case there will always be a current of air from the colder to the warmer region. The fall of rain too, and many other circumstances, may produce an alteration in the temperature, which will be followed by a change in the wind.

The velocity of the wind has been frequently measured with great accuracy, and varies under different circumstances. It has been said of swift horses, such as Childers and Eclipse, that they outstripped the wind, and so they did at its mean rate. But we ourselves can even go faster than the wind in some states; for in calm weather, when its motion is just perceptible, its velocity is not more than one or two miles in an hour, and even a brisk wind does not travel at the rate of more than 15 or 20 miles an hour. Childers, on the contrary, is known to have run at the rate of nearly one mile in a minute, that is at least 50 in the hour, which is equal to the velocity of a storm.

The storms which we experience in these happy climates are as nothing when compared with those dreadful convulsions of nature which are occasionally felt in warmer latitudes, where the fruits of a whole year's labour are often destroyed by a single *hurricane.* These terrible phænomena happen in the West Indies, generally in the rainy season, about the month of August. They are always preceded by an unusual calm; but the storm comes on suddenly, commonly accompanied with rain, thunder, and lightning, and sometimes with an earthquake. Whole towns are made a heap of ruins by one of these hurricanes; fields of sugar-canes are whirled through the air; the strongest trees are torn up by the roots and tossed like stubble; nor can any building be constructed strong enough to afford a shelter from the beating of the storm, and the deluge of wet with which it is accompanied. The island of Jamaica was visited in the year 1780 by this fatal calamity, and the damage which ensued is not to be calculated. The hurricanes in the West Indies have been attributed, with great probability, to some occasional obstruction in the usual and natural progress of the equatorial trade winds.

The *harmattan* is a wind which prevails occasionally during the months of December, January, and February, in the interior parts of Africa, and always blows towards the Atlantic ocean. There are generally three or four returns of it every season; it blows with a moderate force, not quite so strong, indeed, as the sea breeze. A fog or haze always accompanies the harmattan, so that the sun is concealed the greater part of the day, and the largest building cannot be seen at a quarter of a mile distance. The particles which constitute this fog are deposited on the leaves of trees, and on the skins of the negroes, making them appear white. But the most extraordinary property of this wind is its extreme dryness. No dew falls during its continuance (on the average about a week), and the grass is parched up like hay. Household furniture is cracked and destroyed, the pannels of wainscots split, the joints of a well-laid floor of seasoned wood will be opened so as to admit the breadth of a finger between them, and the covers of books, though shut up in a close chest, are bent as if they had been exposed to the fire. Nor does the human body escape; the eyes, nostrils, lips, and palate are parched up, and made very uneasy. Though the air is cool, there is a prickling heat all over the skin; and if the harmattan continues four or five days, the scarf skin peels off. This wind, though fatal to vegetable life, is said to be conducive to the health of the human body. It stops all epidemics; indeed no infection can be communicated, even by inoculation, during its continuance. It relieves patients labouring under fevers, and is remarkable for the cure of ulcers and cutaneous diseases.

The *sirocco* is as deleterious as the harmattan is salubrious. It is common in Italy and the south of France. In the former it is called the *sirocco*, from a common opinion that it blows from *Syria;* in the latter it is called the Levant wind. The medium heat of the atmosphere while it it blows, is one hundred and twelve degrees. It is fatal to vegetables, and often destructive to the human species. It depresses the spirits in an unusual degree; it suspends the power of digestion, so that those who eat a heavy supper, while it continues, are often found dead in their beds in the morning. The sick, at that afflicting period, commonly sink under the pressure of their diseases; and it is customary in the morning, when this wind has blown a whole night, to inquire who is dead.

The *samiel*, or mortifying wind of the deserts near Bagdat, is also dreadful in its effects. At its approach the camels instinctively bury their noses in the sand, and travellers throw themselves as close as possible to the ground till it has passed by, which is commonly in a few minutes. As soon as those who have life dare to rise up, they examine how it fares with their companions, by plucking their arms and legs; for if they are struck by the wind they are often so mortified that their limbs will come asunder. The fatal effects of this wind must depend upon a quantity of putrid vapour with which it is charged, probably from passing over stagnant lakes, or marshes loaden with putrid matter.

Whirlwinds, which are so sportive in their appearance in this country, carrying up straws and other light bodies a considerable height in the air, have been known in the tropical countries to produce most tremendous effects. It is probably a description of them which is known there by the name of *tornados;* these carry up with them the whole materials of a cottage, or even large trees, with the same velocity as our whirlwinds do straws and the lightest bodies. A whirlwind at land is a *water-spout* at sea; at least, both seem to proceed from the same cause. Wherever the air is suddenly rarefied in a particular spot, from electricity or any other cause, a kind of vacuum is created, and the circumambient air rushing at once from every quarter, a conflict of winds takes place, and the circular motion, already noticed, ensues. It is to be observed that, in water-spouts at sea, the water ascends, and does not descend (according to the vulgar notion) from the cloud, which is formed at the extremity of the spout. The water in this case rises, where the vacuum is created by the whirlwind, by the pressure of the atmosphere, as in a common pump. Only the vacuum not being quite perfect, it rises in small drops, and forms the cloud at the upper extremity of the phænomenon. An artificial water-spout may be made in a very easy way. In a stiff paper or card make a hole just wide enough to insert a goose quill, then cut the quill off square at both ends; place the card at the top of a wine glass or tumbler filled with water to within about a quarter of an inch of the lower orifice of the quill. Then apply the mouth to the upper part of the quill, and draw out the air. The water in the glass will then be seen raised in the form of an inverted cone like a water-spout, and not in a continued stream, but broken into drops, and mingled with particles of air.

It is by the agency of the air that water is raised in vapour from the earth to form *clouds.*

You need not be told, I presume, that clouds are water in a suspended state, and so is the common smoke which ascends from our chimneys, the columns of which, in fact, are so many clouds. Vapour is water expanded by heat or fire to the state of an elastic fluid, and it rises in the atmosphere*, because vapour is lighter or less dense than our common air (it is, in fact, fourteen hundred times lighter than the water of which it is composed, whereas common air is only about nine hundred times lighter than water); and it is a rule in philosophy, depending on the principle of gravitation, that when two fluids of different densities are brought together, the lighter will always rise to the surface. It is, however, only near the surface of the earth that the air is denser and more heavy

* There is a constant process of evaporation going on from all bodies on the surface of the earth which contain moisture. In a dry atmosphere the evaporation from the human body is very considerable, but the heat which that carries off is continually recruited by the vital principle, which is wonderfully adapted to resist, to a certain extent, the effects both of a hot and a cold medium, keeping the blood in either, very nearly at the same temperature. When, however, this principle is roused by exercise, and a warm and moist air, or a spasm on the skin obstructs the free passage of the perspirable matter, the blood becomes over-heated, and we feel oppressed. On the other hand, exposure to a keen dry wind, without sufficient exercise, endangers delicate persons, from the too great cooling of the blood.

than water. The vapours, therefore, can only rise to a limited height; and it is generally agreed that there are no clouds at the height of four or five miles in the atmosphere: their usual height, indeed, seldom exceeds a mile, nor very often half a mile. Vapour, by coming in contact with a cold body, can be deprived of its heat, and is suddenly condensed into water again, as in the refrigeratory of a still, where the vapour, confined in a spiral tube, is made to pass through cold water, and is condensed, as in the steam engine, which was noticed in a former lecture.

If, therefore, the vapours in the atmosphere, by ascending into the colder regions of the air, by electricity, or by meeting with cold winds, are deprived of the heat which keeps them in the vaporific state, they will of course be condensed to clouds, and will fall down in the form of *rain*. Perhaps the attraction of the earth, when they approach it, may, in many cases, serve to draw off the superfluous heat, or electricity, and condense the vapours; which may account for its generally raining on the tops of mountains, and for the changes of the weather predicted by the barometer. For when the air is so far rarefied as not to be able to support the column of mercury to a certain height in the tube of the barometer, it is generally regarded as a sure prognostic of rain.

The air in the higher regions being sometimes intensely cold, the vapours immediately after condensation are frozen, and the frozen particles in their slow descent unite at a determinate angle, forming the beautiful feathery flakes of *snow*, each of which is, in fact, a very complicated group of little crystals. *Hail* is sometimes an entire drop frozen in its descent through a colder region, or by means of a rapid evaporation, in which case it is a transparent globule; but much more frequently a common snow flake rolled up in a manner by whirling between two currents forming an opake nucleus, which by its extreme coldness encrusts itself with clear ice out of the vapours it meets with in falling. These rolled snow flakes often fall unencrusted before a severe frost. Angular hailstones are the fragments of larger spheres which have broken in their fall, probably by the expansion of air enveloped in the spongy nucleus.

The *dew*, which falls in a summer evening, is part of the vapour which is raised in the course of the day by the sun's heat; but not being completely dissolved or dispersed in the atmosphere, it is condensed, and falls with the evening's cold. In cool nights the dew often becomes frozen in the form of *hoar frost*.

The atmospherical phænomena will be further explained when we treat of electricity.

LECTURE VIII.

EXPERIMENTAL PHILOSOPHY.

ELECTRICITY.

If the electrical fluid is not caloric, or the matter of fire, it resembles that element in so many of its phænomena and effects, that there is reason to believe it a combination of it with some other substance. But of the nature of that combination we are at present ignorant. To mortify the pride of man, philosophy leaves some things unexplained: the really ignorant are those who think they can penetrate into every secret of nature; whereas the truly wise will see that there is much placed out of the reach of human comprehension, and many things yet left to be discovered by the industry and the patience of man.

The electric matter resembles caloric or fire in its most usual effects, the power of igniting or setting on fire inflammable bodies; in melting metals; in the emission of light; and in the velocity of the electric spark. Friction, which is known to produce heat and fire, is also the most powerful means of exciting electricity; heat also extends itself most rapidly in humid bodies and metals, and these are the best conductors of electricity; and as caloric is the most elastic of all fluids, and perhaps the great cause of repulsion, so the electrical repulsion may, perhaps, be referred to the same principle.

On the contrary, there are some facts which seem to prove that the electric matter is somewhat different in its nature from caloric. The electric matter affects the organs of scent; its progress may also be arrested by certain substances which, on that account, are called non-conductors; glass, in particular, which admits the passage of both heat and light, stops the course of the electric matter: on the contrary, the electric fluid will adhere most tenaciously to some other bodies, without diffusing itself even to those which are in contact with them: thus an electric spark has been drawn by a wire through the water of the river Thames, and has set fire to spirit of wine on the opposite side.

The principal phænomena of electricity are first, The electrical attraction and repulsion. Secondly, The electrical fire rendered visible: and, thirdly, The power which certain substances possess of conducting the electrical matter; whence arises the distinction between conductors and non-conductors, or non-electric and electric bodies. The electric are those which are capable of being excited, such as glass, amber, &c. but do not conduct; the non-electrics are such as conduct the electric matter, but cannot be excited to produce it, such as metals, stones, and all fluids.

These phænomena were not, however, all discovered at once; on the contrary, it was by slow degrees that philosophy became acquainted with the properties of this surprising fluid. It was, however, long known that amber* and some other matters, when rubbed on a soft and elastic substance, had a power of attracting feathers, straws, or other light bodies. We may, without either pains or cost, make the experiment: by taking a piece of sealing-wax, and rubbing it quickly upon a coat sleeve, or any piece of woollen cloth, we shall find that it will readily attract hair, feathers, chaff, &c. A smooth bubble of glass will answer still better.

Sulphur is also a body that is capable of exercising this power of attraction; and to observe more perfectly its effects, Otto Guericke, burgomaster of Magdebourg (the same who is mentioned in a preceding lecture, as having afforded hints for the construction of the air-pump), made a large globe of sulphur, which he fixed in a wooden frame, and, by whirling it about rapidly, and rubbing it at the same time with his hand, he was enabled to perform several experiments. This may be regarded as the first electrifying machine. He observed that a body which was attracted by his globe was afterwards repelled by it, but that if it touched another body, it became after that capable of being attracted again. Thus he was able to keep a feather sus-

* Amber, *electron* in Greek, whence the name electricity.

pended over his globe; but if he drove it near a linen thread, or the flame of a candle, it instantly recovered its propensity to approach the globe again. This fact is now explained; the feather, by being attracted by the globe, and especially when in contact with it, becomes charged, or loaded with the electric matter; when it touches or comes very near a body which is not charged with electricity, it parts with its share to that body, and returns again to receive a fresh supply, if "within the sphere of attraction," that is, within those limits whither the attractive powers of the globe extend.

This philosopher was enabled to remark the hissing noise which a stream of the electric matter produces, and he had a glimpse of the electric light; but Dr. Wall, an English philosopher, observed it more clearly. By rubbing amber upon a woollen cloth in the dark, he found that light was produced, attended by a hissing or rather a crackling noise. Mr. Hawksbee, another of our countrymen, observed the same thing of glass; and he constructed a kind of machine, which enabled him to put a glass cylinder in motion.

Thus the electric attraction and the electric light were proved by experiment; but it was reserved for Mr. Grey, a pensioner of the Charter-house, to make the distinction between those bodies which are capable of being excited to electricity, and those which are only capable of receiving it from others. After attempting in vain to give the power of attraction to metals, by rubbing, hammering, and heating, he conceived a suspicion, that as a glass tube, when rubbed in the dark, communicated its light to other bodies, it might possibly be made to communicate also its power of attraction. He provided himself, therefore, with a glass tube three feet five inches long, and near an inch and one-fifth in diameter. The ends of the tube were stopped with cork, and he found that when the tube was excited by friction, a feather was attracted as powerfully by the cork as by the tube itself. To convince himself more fully, he procured a small ivory ball, which he fixed to a stick of deal four inches long, and thrust into the cork; and he found that it attracted and repelled the feather even with more vigour than the cork itself. He afterwards fixed the ball to a longer stick, and even to a piece of wire, with the same success. Lastly, he attached it to a piece of packthread, and hung it from a high balcony, where he found that, by rubbing the tube, he enabled the ball to attract light bodies in the court below.

His next attempt was to examine whether this power acted as well horizontally as perpendicularly. With this view he made a loop of cord, which he hung to a nail in one of the beams of the ceiling, and ran his packthread, which had the ivory ball at the end, through the loop; but in this state he found, to his utter mortification, that his ball had totally lost the power of attraction. On mentioning his disappointment to a friend, it was suggested, that the cord which he employed for the loop, through which the packthread ran, might be so coarse as to intercept the electric power. To remedy this, they made the loop of silk, which they considered as stronger, in proportion to its thickness, than the former. With this apparatus they succeeded beyond expectation. As they attributed their success entirely to the fineness of the silk of which the loop was made, they thought they would perform still better by supporting the packthread by a very fine brass or iron wire; but to their utter astonishment, the electric virtue was entirely lost; while, on the contrary, when the apparatus was supported by the silk loops, they were able to convey the power of attraction along a packthread of seven hundred and sixty-five feet in length. It was evident, therefore, that these effects depended upon some quality in the silk, which disabled it from conducting away the electric power, as the hempen cord and the wire had done; and, by subsequent experiments, this hypothesis was amply confirmed.

This little narrative may serve to give a tolerably competent idea of non-conducting and conducting bodies; and we must remember, that those bodies which do not conduct the electric fluid are most capable of exciting it, and are supposed to be naturally charged or loaded with a quantity of it. They have, therefore, been called electrics; such are amber, jet, sulphur, glass, and all precious stones; all resinous substances; and the dried parts of animals (except the bones), such as hair, wool, silk, &c. On the contrary, stony substances in general, fluids in general, alum, pyrites, sulphuric acid, black lead, charcoal, and all kinds of metals are among the non-electrics, or those which conduct the electric fluid.

Soon after the discoveries, as above related, of Mr. Grey, both the English and German philosophers contrived means of accumulating the electric matter and increasing its effects. Not only the electric fire was rendered visible, but it was made to pass from one conducting body to another. Spirits and other inflammable matters were easily set on fire by the electric spark; and animal bodies were made to feel what is called the electric shock—that is, the uneasy sensation felt on the electric fluid passing through any part of our bodies.

The machines at first constructed for producing the electric fire were made in a very com plex form. It is now found that it may be excited by much simpler means; and the machine exhibited in plate 9 (fig. 35.), though extremely simple, is very powerful. In this figure A B C represents the board on which the machine is placed. D and E are two vertical supports, which sustain the glass cylinder F G H I. The axis of the cap K, in which the cylinder is fixed, passes through the support D, and it is turned by a winch or handle, as represented in the plate. The axis of the other cap is inserted in the supporter E; O is the *glass* pillar to which the cushion is fixed. At the bottom of the pillar O is a brass screw T, which brings the cushion at the top of the pillar nearer to the cylinder or removes it further, at the discretion of the operator, when he wishes to increase or lessen the pressure.

Y Z is the prime conductor, which by means of metallic points takes the electric matter immediately from the cylinder; and in order that the electric fluid may be accumulated upon the conductor, and not run off to the earth, the conductor is *insulated*, that is, placed upon a non-conducting body, which will not attract the fluid away from the conductor. The insulating substance, in this case, is a *glass* pillar, L M (glass being the most convenient substance for this purpose), and V X is the wooden foot or base of the glass pillar. The conductor is always of metal, at least externally, as metals are found to be the most powerful of the conducting bodies. They are commonly made of wood, and cased over with tin-foil.

When electrical machines were first constructed, instead of a cylinder, a glass globe was made use of; and when this was turned, the hand of the operator was applied to it, and afterwards a piece of glove leather; but the most effectual and easy means is now found to be a leather cushion, covered or smeared over with what is called an *amalgam*, or a mixture of tin and mercury. A small chain is also annexed to the apparatus, in order to make a communication with the earth; which is always necessary, as the electrical fluid is all supposed to be ultimately derived from the earth. When the chain is laid over that conductor which communicates with the cushion, then that conductor is no longer insulated, but an immediate communication is established with the earth: if, on the contrary, the chain is taken from it, and laid over the prime conductor, different effects are produced, which we shall endeavour hereafter to explain.

It is scarcely necessary to add that the electrical power is excited by turning the cylinder pretty quickly round, while it rubs against the cushion. On turning the cylinder for a little time in this manner, we find that sparks may be drawn by the knuckle from the prime conductor, which is then charged or loaded with the electric matter, and this matter has a kind of sulphureous smell. Again, if a metallic plate is placed at some distance beneath the conductor, and some light bodies, such as feathers, straws, or little images of men and women cut in paper are presented to it, they will be first attracted to the conductor, they then become in effect conductors themselves, and, as soon as charged with the electrical matter, they will be *repelled;* they will then fly to the plate, and discharge the electricity they have received, and then be in a state to be attracted again, when they will again fly up to the conductor; and a very curious effect is produced by the little images being thus put in motion, as if by a kind of magical power.

The human body itself may, in this manner, be made a conductor; but to enable it to accumulate any quantity of the electric matter, the man must be *insulated*, that is, some non-conducting substance must be placed between him and the earth, and he must stand upon a cake of rosin, wax, or sulphur, or upon a stool with glass legs. If, then, he lays his hand upon the conductor, his body will be filled with the electrical matter, and sparks may be drawn from any part, upon being touched by another person; and each spark will be attended with a crackling noise, and a painful sensation to each party. If, in the same circumstances, spirit of wine is presented to the man in a metal spoon, when he touches it with his finger it will be set on fire; and gunpowder, or any other very inflammable substance, may be kindled in the same manner.

As metals are the most powerful conductors of electricity, if a wire of iron or any other metal be suspended by silken cords (that is, *insulated)*, the electric matter may be conveyed to an immense distance through dry air; for air is a non-conducting substance when not moist, and therefore will not draw away the electric matter. In this manner some French philosophers conveyed the electric fire through a circuit of three miles. Though water is a conductor, yet, not being so powerful as metals, the late Dr. Watson conveyed (as has already been observed) the electric fire, by means of a wire, through the Thames, and it set fire to spirit of wine on the opposite side.

The most powerful means, however, of accumulating the electric fluid is found to be the Leyden phial. This discovery was made about the year 1745, by Mr. Von Kleist, dean of the cathedral of Camnin. He found that a nail or a piece of iron wire, inclosed in an apothecary's phial, and exposed to the prime conductor, had a power of accumulating the electric virtue, so as to produce the most remarkable effects; and he soon after ascertained that a small quantity of fluid added to it increased the power. The fact is, that if glass is coated on one side with any conducting substance, that substance will accumulate the electrical matter, because it is intercepted by the glass, and prevented from diffusing itself; the form of the glass is of little consequence. The Leyden phial or jar, as at present employed, is a thin cylindrical glass vessel, such as fig. 39, about four inches in diameter, and coated within and without, to within two inches of the top, with tin-foil or any conducting substance. Within the jar is a metal wire, with a knob at the top of it, which wire communicates with the inner coating of the jar. To discharge the phial, a communication must be made (either by what electricians call a conducting or discharging rod D, or any other fit instrument) between the inner and outer coating of the jar. Its effects may be proved by placing the phial or jar (fig. 39.) on an insulated stand, bringing the coating in contact with the conductor, and then turning the machine. If in this case we apply the discharging rod D, we shall find there will be no explosion, because both sides being insulated, the phial was not charged; but if a small chain is suspended from the brass knob of the phial, and communicates with the table, the phial will then be charged, and the explosion will be considerable. The reason of this has been explained before, as it was proved that the electrical matter is derived from the earth.

The shock which is given by the Leyden phial is much more powerful than that from the largest conductor; but this power is greatly increased by uniting together the force of several jars, in what is called an electric battery (see fig. 40.). The bottom of the box in this apparatus is covered with tin-foil, to connect the external coatings of the jars; and the inside coatings are connected by the wires *a*, *b*, *c*, *d*, *e*, *f*, which meet in the large ball above. There is a hook at the bottom of the box, by which any substance may be connected with the outside coating of the jars; and a ball B proceeds from the inside, by which the circuit may be conveniently completed. By the discharge of an electrical battery a large dog may be killed in an instant, and the strongest man will be knocked down and deprived of sensation; a wire of some magnitude may be melted, and most of the phænomena of lightning are produced, but on a smaller scale.

LECTURE IX.

EXPERIMENTAL PHILOSOPHY

ELECTRICAL PHÆNOMENA AND GALVANISM.

SOME of you will, I doubt not, be disposed to remind me, that I have neglected to explain why the electrical machine exhibited different effects when the chain, which communicates with the earth, was put over the prime conductor, from those which take place in its ordinary mode of operation, when the chain was connected with the cushion.

In a very early stage of the science, two kinds of electricity were observed, or, according to Dr. Franklin's theory, two different effects from the same cause. A ball of rosin or sealing-wax, and a globe of glass, when excited, will each of them electrify; but the electricity produced from each will differ in some of its effects. Thus, if we electrify two cork balls, suspended by silken threads, with the same substance, either glass or sealing-wax, they will mutually repel each other; but if one of them is electrified with glass, and the other with sealing-wax, they will be mutually attracted. From this circumstance it was conjectured at first, that there were two kinds of electricity; that from glass was called the *vitreous,* and that from resinvus substances or sulphur was termed the *resinous* electricity. Another circumstance which served to distinguish them, was the different appearance of the electric light. A divergent cone of light, resembling a painter's brush, distinguished the *vitreous* electricity, while a single globe or ball of clear light was the mark of the *resinous.* In process of time, however, it was discovered that these different phænomena depended rather on the surface than the composition of the electric; for glass, when the smooth surface was destroyed by being ground with emery, and being rubbed with a smooth body, exhibited all the appearances of the *resinous* electricity; yet afterwards, when it was greased and rubbed upon a rough surface, it resumed its former property. It was therefore concluded, upon various experiments, that the smoother of two bodies, upon friction, exhibits the phænomena of the vitreous electricity, and the contrary.

M. Coulumb proposed another theory. He considered the electric matter as composed of two distinct fluids, which are neutralized the one by the other in the ordinary state of bodies, but which separate when the bodies are electrified. Such a theory, however, only serves as a vehicle for reasoning: the experiments establish two distinct modes of operation; and they may be explained with nearly equal facility by either of the hypotheses.

When any body contains a superfluous quantity of the electric fluid, it is (according to the Franklinean theory) said to electrify *positively* or *plus;* when it contains less than its proper share, it is said to be negative or electrified *minus,* that is, some of its electricity is taken from it. That electricity, therefore, which was before called the vitreous, Dr. Franklin calls *positive* electricity; and that which was termed the *resinous,* he considers as *negative* electricity. If, therefore, a rough and smooth body are rubbed together, the smooth body in general will have the positive electricity, and the rough the negative. Thus, in the ordinary operation of the electrical machine, the cylinder is positively electrified or *plus,* and the rubber negative or *minus;* and the redundancy of the positive electricity is sent from the cylinder to the prime conductor. This, however, is supposing the chain, which communicates with the earth, to be at the same time in contact with the rubber; for as the earth is the great repository of electrical matter, if the chain is removed, and put over the prime conductor, these effects will be reversed, and the prime conductor will then be negatively electrified or *minus,* and the rubber will be *plus* or positive *.

* Whether the theory of Franklin be adopted, or whether the hypothesis of two distinct fluids be retained, signifies nothing as to the *facts,* it simply regards the manner of explication. On either hypothesis, the *fact*

That the electrical matter is possessed of force, even while it proceeds in a stream imperceptible to our senses, is evident from an easy experiment. To the under part of the Leyden phial an apparatus is often adapted, as in fig. 38. It consists of the wire *b c*, and a brass fly at the top. While the bottle is charging the fly will turn round, and when it is charged it will stop. If the top of the bottle is touched with the finger, or any conducting surface, the fly will turn again till the bottle is discharged. The fly will electrify cork balls positively while the bottle is charging, and negatively while it is discharging. A similar effect is observable in what is called the electrical bells (fig. 37.). In this apparatus three small bells *a b c* are suspended from a narrow plate of metal, the two outermost *a c* by chains, and that in the middle *b* (from which a chain passes to the floor) by a silken thread. Two small knobs of metal *d e* are also hung by silken threads on each side of the bell, in the middle, which serve for clappers. When this apparatus is connected with an electrified conductor, the outermost bells, suspended by chains, will be charged, will attract the clappers, and be

remains, that electric action follows the inverse ratio of the square of the distance; as has been decisivelyproved by Coulomb and others. It is also an established fact, that the whole fluid of a conducting body is diffused about its *surface*. Electrical facts are well confirmed; but the theory, like that of magnetism is, as yet, uncertain.

struck by them; and the clappers then becoming, in their turn, electrified, will be repelled by these bells, and attracted by that which is in the middle, and their electricity will be then attracted away by the chain which passes to the floor. After this the clappers will be again attracted by the outermost bells, and thus the ringing will be continued as long as the conductor is charged. An apparatus of this kind is usually attached to the conducting rods, which are fixed to the gable-ends of houses to protect them from lightning, and thus serve to give notice of a thunder storm.

The instrument called an electrometer (fig. 36.), which is commonly used for measuring the quantity of electricity contained in any body, is constructed on a similar principle. It consists of a vertical stem L M which terminates in a round top L like a ball. It may be fixed in one of the holes of the conductor, or at the top of a Leyden phial. To the upper part of the stem a graduated semicircle is fixed, as well as the index, which consists of a very slender piece of wood, which reaches to the centre of the graduated arch, and at its extremity there is a small pith ball. When the body is electrified, the index recedes more or less from the pillar, and the degree is ascertained by the gradations on the arch.

Electricity accelerates the evaporation of liquors and the perspiration of animals. There is reason also to apprehend that it is not without effect upon the vegetable creation, as from some experiments we are led to conclude that plants which have been electrified vegetate earlier and more vigorously than those which have not been subjected to its influence.

Electricity is, indeed, a most powerful agent in nature, and we are probably not yet acquainted with all its effects. It is, however, in the atmospherical phænomena that these effects are most apparent and most tremendous. It is to Dr. Franklin that we are indebted for the interesting discovery, that the cause which produces THUNDER and LIGHTNING is precisely the same with that which produces the ordinary phænomena of electricity.

This eminent philosopher was led to the discovery by comparing the effects of lightning with those produced by an electrical machine, and by reflecting that if two gun-barrels when electrified will strike at two inches with a loud report, what must be the effect of ten thousand acres of electrified cloud? After much thought upon the subject, he determined to try whether it was not possible to bring the lightning down from the heavens—a thought at once daring and sublime! With this view he constructed a kite, like those which are used by school boys, but of a larger size and stronger materials. A pointed wire was fixed upon the kite, in order to attract the electric matter. The first favourable opportunity he was impatient to try his experiment, and he sent his kite up into a thunder cloud. The experiment succeeded beyond his hope. The wire in the kite attracted the electricity from the cloud; it descended along the hempen string, and was received by an iron key attached to the extremity of the hempen string, that part which he held in his hand being of silk, in order that the electric fluid might stop when it reached the key. At this key he charged phials, with which phials thus charged he kindled spirits, and performed all the common electrical experiments.

Thus it became evident that the cause of those terrible convulsions of nature, which, in warm climates especially, are attended with such tremendous effects, is no other than a superfluous mass of electrical matter, collected in those immense watery conductors, the clouds; and that this matter is discharged when an electrical cloud meets with another which is less powerfully charged, or when it is brought sufficiently near to the earth to be within the sphere of the electrical attraction. This fact may be proved at almost any time, but particularly in a sultry summer's evening, by repeating Dr. Franklin's experiment with the kite. Some caution, however, must be used in making the experiment; and it will succeed better if a small wire is twisted in with the hempen string by which the kite is held; indeed Mr. Walker, in his Lectures, recommends to fly the kite with wire instead of a string, which, he observes, may be coiled upon a strong rod or bar of solid glass, held in both hands. Sparks may, in this manner, be taken from the wire or string, as from a common electrical machine. For security, however, a key must be suspended by a wire from that which is coiled up, so as to touch a half-crown, or a plate of metal lying on the ground. If the key is then lifted a little from the plate, a stream of fire will be seen proceeding from the key to the plate; but if a sensation like a cobweb on the face takes place, it will be prudent to throw down the glass bar, and leave the kite to itself*. Electricity may be again attracted from the atmosphere, if a long wire screwed into the knob of a Leyden bottle, and pointed at the extremity, is held aloft in the air; and if this experiment is made in the night-time, when thunder and lightning are near, a star will appear at the point of the wire, and if the bottle is touched with the other hand, a shock will be received. A man also standing upon a glass stool, and holding in his hand a fishing-rod coated with tin-foil, or any long metal instrument, aloft in the air, will generally be more or less charged with electricity, in proportion to the state of the atmosphere, and

* Professor Richmann, of Petersburgh, in consequence of disregarding the due precautions, was killed while he was conducting the experiment of drawing electricity from a thunder cloud.

sparks may be drawn from his body as if he had been electrified in the usual manner.

Thunder storms in this country are seldom attended with fatal effects, yet it is desirable to be made aware of their approach. They are generally observed to happen when there is little or no wind, and are preceded by one dense cloud or more, increasing very rapidly in size, and rising into the higher regions of the air. The lower surface is black and nearly level, the upper parts are arched and well defined; sometimes many of them appear piled one upon another, all arched in the same manner. At the time this cloud rises, the air is generally full of small separate clouds, motionless, and of whimsical shapes. These gradually are drawn towards the thunder cloud, and when they come near it their limbs mutually stretch towards each other, and then coalesce. Sometimes, however, the thunder cloud swells and enlarges without the addition of these clouds, from its attracting the vapours of the atmosphere, wherever it passes. When the thunder cloud is grown to a great size, the lower surface becomes rugged, parts being detached towards the earth, but still connected with the rest. About this time also it seems to sink lower, and a number of small clouds are driven about under it, in very uncertain directions. It is while these clouds are most agitated that the rain or hail falls in the greatest abundance.

While the thunder cloud is swelling, and extending its branches over a large tract of country, the lightning is seen to dart from one part of it to another, and often to illuminate its whole mass. When the cloud has acquired sufficient extent, the lightning strikes between it and the earth in two opposite places. As the lightning continues, the cloud dilates, till at length it breaks in different places, and displays a clear sky.

The clouds, however, are sometimes negatively electrified with respect to the earth, and in this case the lightning is supposed to proceed from the earth to the cloud; but the mischievous effects are the same, and, in fact, there is reason to think that this is a rare case.

During a thunder storm the safest place is in a cellar; for when a person is below the surface of the earth, the lightning must strike it before it can reach him, and its force will therefore probably be expended on it. When it is not possible to retreat to a cellar, the best situation is in the middle of a room, not under a metal chandelier, or any other conducting surface; and it is adviseable to sit on one chair, and to lay the feet up on another; or it would be still better to lay two or three beds or mattresses, one upon another, in the middle of the room, and place the chairs upon them, the matters (viz. hair and feathers) with which they are stuffed being non-conductors. Persons in fields should prefer the open parts to any shelter under the trees, &c. The distance of a thunder cloud, and consequently the degree of danger, is not, however, difficult to be estimated. As light travels at the rate of seventy-two thousand four hundred and twenty leagues in a second of time, its effects may be considered as instantaneous within any moderate distance; but sound, on the contrary, is transmitted only at the rate of three hundred and eighty yards in a second. By accurately observing the time, therefore, which intervenes between the flash, and the noise of thunder which succeeds it, a very near calculation may be made of its distance. Or, the distance may be very well estimated by means of the pulsations in the wrist, allowing five and a half to a mile; and in the same proportion for any other number of pulsations in the interval between the flash and the thunder.

The discovery of Dr. Franklin, which ascertained the identity of lightning and the electric fluid, suggested to the same philosopher the means of preserving buildings from lightning, by means of metallic conductors attached to the outside of high buildings. As these are now common, it is unnecessary to describe them. The principle on which they are constructed rests on the well-known fact of metallic bodies being better conductors of the electrical fluid than any others. The conducting rod is pointed at the top, in order the more gradually to attract the electricity from the clouds and the atmosphere; and the upper part should be made of copper, to prevent its rusting, and the remainder painted. The conducting rod should not be too slender, and should extend in the earth beyond the building, to convey the electric matter clearly away; and if it terminates in a pool of water, which is one of the best conductors, it will be still safer.

I shall conclude this lecture by a short view of that branch of science (for such it is now universally allowed to be) which has been termed GALVANISM, or VOLTAISM.

It was long known that common electricity could excite a tremulous or convulsive motion in dead animals; but about the year 1791 it was discovered that these effects could be produced without the aid of an electrical apparatus, and apparently by different means, and hence they were at first ascribed to a different power in nature.

This discovery, like some others of importance in philosophy, was the effect partly of accident. Dr. Galvani (whence the term Galvanism), professor of anatomy at Bologna, having observed certain involuntary motions or contractions in the muscles of some dead frogs, which had been hooked by the back-bone and suspended from the iron palisades of his garden, was induced to examine more minutely into the cause of these motions; and he found that he could produce them at pleasure, by touching the lifeless animal with two different metals, provided the metals were, at the same time, in contact with each other. From latter observations it appears that these contractions may be excited by one metal, assisted by other substances, or even without any metal whatever. The metals, however, are the most certain agents, but they will produce no effect without the intervention of some fluid which has a chemical action on one or both of the metals.

The experiment may be tried upon any animal recently dead; but what are called the *cold-blooded* animals, that is, those which have their blood of a temperature not higher than that of the atmosphere, such as reptiles and fishes, retain this sensibility much longer than others; dead frogs for instance will retain it for several hours, and sometimes for a day or two.

To give the experiment proper effect some preparation is however requisite; and as the galvanic influence acts principally on the nerves, it is necessary that *they* should be exposed to one of the metals: it is made most successfully on the hind legs of a dead frog.—To this end we have only to cut them off with a small bit of the spine attached to the nerves of the thigh, as in plate X. fig. 41, where GH are the lower limbs, thus adhering to a small piece of the spine AB, by means of the crural nerves CD. The legs must be skinned in order to lay bare the muscles, and a small piece of tin-foil wrapped round the spine A, B. If we then hold one of the legs in our fingers, and let the other be suspended with the bundle of nerves and spine hanging upon it, and then interpose a piece of silver, as half-a-crown, between the lower thigh and the nerves, so that it may touch the former with one surface, and the tin-foil which is wrapped round the spine with the other, we shall find the lower leg convulsively agitated, so as even sometimes to strike against the hand which holds the other.

Living animals, when thus placed between two different metals which touch each other, will also be convulsively agitated. Or you may make the experiment upon yourselves in a very innocent way, so that the taste and even the sight may be affected by it. Take, for instance, a piece of metal (zinc is the best), and lay it on your tongue, and another piece of metal, as a shilling or half-crown under it, make the edges of the two metals touch, and you will immediately experience a kind of irritation and a taste like copper in your mouth. If, again, in a dark place one of the metals is applied to your eye and the other up your nostril or in your mouth, upon bringing the metals in contact a faint flash of white light will appear before your eyes. Nay the same effect will be produced, and the light will still appear, if one of the pieces of metal is put up your nostril, and the other upon the tongue; or even if one is put between the upper lip and the gums, and the other on the tongue; only remarking that the metals must be different —silver and zinc are the best for the purpose.

These experiments have served to explain many facts which were well known, but the reason of which was not before discovered. It had been long observed, that porter and malt liquors have a different and a pleasanter taste when drunk out of metal than out of glass or earthenware; and on the contrary that water out of a metallic cup has a disagreeable and metallic taste; these effects are now known to be owing to a slight galvanic shock, such as is experienced by placing the tongue between two metals in contact.

Mixtures of metals have been long known to corrode each other, while pure metals have remained unchanged;—thus the Etruscan inscriptions engraven on pure lead are preserved to this time, while medals of lead and tin of no great antiquity are much defaced. The copper sheathings of vessels when fixed on with iron nails become very soon corroded; and I believe it is now customary to fix them to the bottoms with copper nails. These effects are owing to the action of the metals on each other, or rather on the moisture which is interposed, which, being decomposed by the action of the metals, is separated into its constituent parts (oxygen and hydrogen), and one or both of the metals become oxidated, rusted, or corroded.

The conductors of electricity are also conductors of galvanism:—these are divided into two classes; the dry, such as metallic substances and charcoal; and the wet, as water and certain other fluids.

The galvanic influence cannot be powerfully excited without a combination of three conductors, two of one class and one of another. When two of the three bodies are of the first class (as two metals, zinc and silver, or zinc and copper with water or an acid), the combination is said to be of the first order. But it is an indispensable requisite that one of the three conductors should have a chemical action on one or both the others: thus water, as containing oxygen, has an action on the metals; if it is impregnated with oxygen gas its action is increased, and much more powerful than that of water deprived of air by boiling; and if a small quantity of any of the mineral acids is added, the effect will be still greater. Thus the agitation ore xcitement occasioned by the action of an acid principle is the source of galvanism, as the excitement occasioned by friction is of electricity.

Yet it will appear by an easy experiment that the galvanic influence has a powerful agency in directing and increasing this chemical action. A glass tube (fig. 42.) about 4 inches long has its extremities completely stopped by two corks, A, and B. An oblong piece of zinc, CD, is thrust through one of the corks, and projects within and without the tube. In the other cork is fixed a silver wire projecting with the extremity F, within the tube, while its other extremity is bent so as to come near the projecting part of the zinc C. If then the tube between the corks is filled with water impregnated with a small quantity of muriatic acid, the zinc will be immediately acted upon by the diluted acid, and bubbles of gas will be seen to proceed from it, but the silver wire EF remains untouched. If then you bend the silver wire FG so that its end may touch the zinc at C, you will find not only that the fluid acts more strongly upon the zinc at D, but that the silver at F is also strongly acted upon, as appears by the evolution of gas, &c. This is what is called a galvanic circle, and this circle is *completed*, in the technical language of this science, by bringing the silver wire in contact with the zinc at C.

The effects from simple galvanic circles, and the analogy between the phænomena of galvanism with these of electricity, suggested the idea of extending the combinations, and forming what are now called galvanic batteries. The first and simplest of these were formed of round pieces of zinc and silver with pieces of cloth or leather rather smaller, and moistened with water or diluted acid, interposed in the manner of fig. 43, where the silver, zinc, and wet cloth are marked by the letters S, Z, W. This was at first called the galvanic pile, from its form.

The most convenient form for a galvanic battery, however, was soon afterwards found to be that represented in fig. 44. It consists of an oblong vessel or trough of baked wood of different sizes, according to the strength of the intended battery. In the sides of the trough there are grooves, in each of which are placed a double metallic plate, commonly of zinc and copper soldered together, thus dividing the whole of the trough into a number of distinct cells, so cemented that no fluid can pass from one to another. The cells are afterwards filled with water (to which at present a small quantity of nitric or muriatic acid is added to increase its action on the surfaces of the two metals thus presented to it in each cell): two or more of these batteries may be joined by connecting them with a piece of wire.

If, when the battery is thus charged and the diluted acid begins to act, you apply a finger of each hand (a little moistened, the better to conduct the electricity) to each extremity of the trough, a shock will be felt such as that communicated by a Leyden phial, in proportion to the extent of the battery. The mode of applying its power to other purposes is as follows: ACDEF is a wire which communicates with the last plate of the battery at A. BKIGH is another wire which communicates with the last plate at B. DEHI are two glass tubes through which these wires pass to enable the operator to direct the ends of the wires without drawing off the electricity. If a thin metallic body, as gold or silver leaf, or tin-foil, is placed between the ends or extremities of the wires, it will be melted; gunpowder will be exploded, or combustible bodies will be set on fire; the muscles or limbs of dead animals will also be convulsively agitated.

To prove that the agency of electricity and galvanism is essentially the same, it is only necessary to mention that a common coated jar, or even an electrical battery, may be almost instantaneously charged from a galvanic battery. It is however to be remarked that the electrical virtue seems to be more diffused, but more permanent, in a galvanic, and more concentrated in a common electrical battery.

The electrical energy is not confined to the substances we have already specified. In the mineral kingdom, the tourmalin, a stone found in the East Indies, by being merely heated, exhibits most of the electrical phænomena.

In the animal kingdom it has long been known that rubbing the back of a cat will produce sparks in the dark. But however this effect may be deemed superficial, and attributed to the hair, there are some other animals which have this virtue more extensive and more powerful. The torpedo, a kind of ray, communicates a strong shock when touched, and the shock is greatly increased by touching it with both hands, and thus completing the circle. The gymnotus, or electrical eel, found in the rivers of Guiana, possesses the same power, but in a superior degree. It seems also to depend on the will of the animal. The electric organs both in this and the torpedo, each of which is furnished with a pair, bear a strong resemblance to the galvanic trough or battery.

In point of *theory*, galvanism is as much afloat as either magnetism or common electricity. Three different theories of the galvanic battery have been proposed. 1. That the galvanic pile is entirely *electrical*. 2. That it is altogether *chemical*. 3. That electricity produces the phænomena, but is, itself, evolved by chemical action. The first of these theories was advanced by Volta; the second by Donovan; the third by Wollaston, and defended by Dr. Bostock.

It has been ascertained by unequivocal experiments that the galvanic pile never acts unless when one of the metals which compose it has been oxydized; and that its energy only continues as long as the oxydizing process goes on: hence Volta's theory is evidently imperfect.

The most cursory attention to the galvanic pile will suffice to demonstrate that it never acts except the circle be completed; that is, unless there be a current of electricity: and this seems to set aside Donovan's theory. Whence it would seem to follow, that *both* chemical decompositions and a current of electricity are necessary to constitute the galvanic pile. They who wish farther to investigate this curious subject may advantageously consult Dr. Bostock's History of Galvanism.

LECTURE X.

EXPERIMENTAL PHILOSOPHY.

LIGHT.

In considering the nature of light, a difficulty presents itself similar to that which occurred with respect to the electrical fluid. Some philosophers have been disposed to consider the matter of light as essentially different from elementary fire, while others have regarded them as intrinsically the same matter, only exhibited in different states. A late writer on these subjects conjectures that light is *diluted fire*, that is, fire weakened and diffused as spirits when mingled with water; and another terms it fire in a *projectile state*, that is, its particles are separately projected, and, in truth, at an immense distance from each other, whereas in culinary fire it is collected and condensed. It is a circumstance which not a little favours this latter opinion, that light may be collected and condensed by what is called a burning-glass, so as to burn like the fiercest flame. On the contrary, flame itself may be so diluted or diffused as to be perfectly innoxious. "The flame," says Dr. Goldsmith, "which hangs over burning spirit of wine, we all know to scorch with great power; yet these flames may be made to shine as bright as ever, yet be perfectly harmless. This is done by placing them over a gentle fire, and leaving them thus to evaporate in a close room without a chimney: if a person should soon after enter with a candle, he will find the whole room filled with innoxious flames. The parts have been too minutely separated, and the fluid, perhaps, has not force enough to send forth its burning rays with sufficient effect."

It is not, however, my intention in these lectures to involve you in the intricacies of theory, or to pursue speculative inquiries at the expense of useful facts. It will be more profitable to detail and explain the properties of light than to waste our time in conjectures on its essence. The most remarkable properties of light, then, are, first, its *velocity;* secondly, its *rarity;* thirdly, its force or *momentum;* fourthly, the property of being always detached in *straight* lines; fifthly, *refraction;* and, sixthly, the *reflection* of light.

I. The velocity of light is such as may well astonish the inexperienced student, when he is told that in the very short space of a *moment,* or a second of time, a ray of light travels the immense extent of *one hundred and seventy thousand miles.* The manner in which the velocity of light is calculated is not less ingenious than the discovery is surprising. It was by observing the eclipses of Jupiter's satellites, and it will be amusing to you to observe the process by which the calculation is accomplished. When the earth, in going its annual revolution round the sun, is at C (plate XI. fig. 45), an eclipse is observed of one of the satellites of Jupiter, which thus regularly suffers eclipses, at intervals of about forty-two hours and a half. If the earth never left C, but continued there immoveable, we should regularly see the satellite eclipsed at the expected interval of forty-two hours and a half; and also in thirty times that number the spectator would see thirty eclipses. But the earth is not fixed; let us, then, farther suppose that the earth in moving through half its orbit from C, the place of conjunction, has just placed itself in opposition, near D, that is, where it would be situated behind the sun relatively to Jupiter. If light had no progressive motion, a spectator on our globe would see the first satellite of Jupiter emerge from the shadow after a period equal to as many times $42\frac{1}{2}$ hours, as there would be eclipses after the moment of conjunction. But this does not happen: for the spectator at D sees the termination of the eclipse about sixteen minutes later than the calculation predicts; so that, in all the intermediate positions between C and D, the difference as far as this limit has been continually increasing. Now C D, the rectilinear distance between these two positions, is equal to the diameter of the earth's orbit, that is, to about 190 millions of English miles. This space, therefore, is passed over by light in 16 minutes; so that, assuming it to move uniformly, we find, by an easy proportion, the space passed over by light in a second to agree with what we have just stated. This discovery we owe to Roemer, a Danish astronomer, and it is extremely interesting and important.

Such, then, is the rapidity with which these rays are darted forward, that the journey they perform thus in less than eight minutes, a ball from the mouth of a cannon would not complete it in several weeks. But here it may be said, If the velocity of light is so very great, how is it that it does not strike against objects with a monstrous force? If the finest sand (the objector may continue to observe) was thrown against our bodies with the hundredth part of this velocity, each grain would be as fatal as the stab of a stiletto: How then is it, that we expose, without pain, not only other parts of our bodies to the incursions of light, but our eyes, which are a part so exquisitely sensible of every impression? To answer this objection, experiment will inform us, that the minuteness of the parts of light is still several degrees beyond their velocity; and they are therefore harmless, because so very small. A ray of light is nothing more than a constant stream of minute parts still flowing from the luminary, so inconceivably little, that a candle, in a single second of time, has been said to diffuse several millions of particles of light. The sun furnishes them, and the stars also, without appearing in the least to consume by granting us the supply. Musk, while it diffuses its odour, wastes as it perfumes us; but the sun's light is diffused in a wide sphere, and seems inexhaustible.

That the motion of light is inexpressibly rapid you may easily convince yourselves, by only giving attention to the firing of a cannon at a considerable distance, and observing the time that elapses between your seeing the flash and hearing the sound. It has been calculated from some very accurate experiments, that sound travels at the rate of one thousand one hundred and forty-two feet, or three hundred and eighty yards, in a second of time; and if you remark, as was before observed, the time which intervenes between your seeing the flash and hearing the noise of the cannon, you will soon perceive how infinitely more rapid light must be in its motions than sound.

II. It is a principle in mechanics, that the force with which all moving bodies strike is conjointly in proportion to the size of those bodies, or the quantity of matter which they contain and the velocity with which they move. Now if we consider the amazing velocity of light, it is evident, that if the separate particles of it were not infinitely smaller than we can conceive, they would be destructive in the highest degree. To illustrate this by a plain example: A few grains of shot, fired out of a musket or fowling-piece, will deprive a large animal, or even a man, of life. How is this? If the shot were thrown by the hand, it would hurt neither the man nor the animal. It is the velocity, the swiftness, with which it is impelled by the force of the powder, that enables it to penetrate solid substances. Now it has been demonstrated that light moves at least *two millions of times* faster than a cannon-ball; and consequently if the particles of light were only equal in size to the two millionth part of a grain of sand, we should be no more able to withstand their force than we should that of sand shot point blank from the mouth of a cannon. How infinitely small must these then be, when it is more than probable they are not equal to a twentieth that size, that is, not equal to the *forty millionth part* of a grain of sand! What an idea does this give us of the works of our infinite Creator, and how little must we seem in our own eyes! O Philosophy, how is it that thou dost not always teach mankind humility!

But we have other proofs not less decisive than this, of the extreme minuteness of the particles of light. When we observe with what facility they penetrate the hardest bodies, glass, crystal, precious stones, and even the diamond itself, through all which they find an easy passage, or those bodies could not be transparent, How extremely small must these particles be! When a candle is lighted, if there is no obstacle to obstruct its rays, it will fill a space of two miles round with luminous particles in an instant of time, and before the least sensible part of the substance is lost by the luminous body. If the whole space were filled with men, every eye would see the candle the moment it was posited in a visible situation. Farther, how small must the particles of light be, when they pass without removing the minutest particles of microscopic dust that lie in their way, and even these minute particles are rendered visible, by reflecting back the particles of light that strike against them!

Small as the particles of light are, it is highly probable that, though diffused through all space, they are separated from each other by distances of much more than *a thousand miles.* This may be inferred as follows: It is an obvious fact, that the effect of light upon our eyes is not instantaneous, but that the impression remains for some time. You may easily satisfy yourselves of this, by shutting your eyes after having looked for some time on a candle, a star, or any other luminous body, when you will perceive that a faint picture will remain of the object for some time. The smallest division of time, that we can well conceive, will be the one hundred and fiftieth part of a second. If, therefore, one lucid part of the sun's surface emits one hundred and fifty particles of light in a second of time, we may conceive that these will be amply sufficient to afford light to the eye without any intermission. You will remember, then, that light travels at the rate of about one hundred and seventy thousand miles in a second; so that, the sun emitting one hundred and fifty particles in that space of time, each particle must be more than one thousand miles distant from the other*. Indeed it is reasonable to suppose that they must be at great distances asunder, or they could not pass so continually as they do in all directions, without interfering with each other.

If, in fact, light were not thus thinly diffused it must be extremely injurious to our organs, since we find that when it is condensed or compressed, as in the focus of a burning-glass, there is no substance that can withstand its force. Gold, when exposed to its influence, is instantly melted, and even the diamond itself, which resists a very intense chemical heat, is suddenly dissolved. To show, however, still more decisively, that the particles of light are naturally in this extremely rare or diffused state, or, in other words, follow each other at an immense distance, it is a well-known fact, that the rays of light, even when collected in the focus of the strongest burning-glass, will not inflame spirit of wine, or any other combustible matter, while they merely pass through it. To make you com-

* This is, in truth, quite an extreme estimate. It appears from the accurate experiments of M. D'Arcy (*Mem. Acad. Par.* 1765), that the impression of light upon the retina continues *two minutes and forty seconds:* and as a particle of light would move thirty-two millions of miles during that interval, constant vision would be maintained by a succession of luminous particles, thirty-two millions of miles distant from each other.

prehend this fact more clearly, I must observe, that whatever light passes through is called *a medium*, and those substances which do not reflect the rays, but which may be seen through, are called *transparent;* those, on the contrary, which intercept or reflect the rays, are called *opaque.* Now a phial in which spirit of wine is contained is a transparent medium, and in that state the spirit will not be set on fire: if, on the other hand, the spirit is poured forth into a spoon, or any opaque vessel, which, in fact, intercepts the rays of light, stops them in their progress, and thus collects them in a mass, it will immediately be inflamed. This, I think, proves, that the particles of light must follow each other at a great distance, and that they must be in the first place compressed together by the force of the burning-glass, and then stopped and condensed by an opaque body, to enable them to produce a considerable degree of heat.

That light may be exceedingly diluted, as well as condensed, we may easily perceive; for the light of the glow-worm, of rotten wood, and of what are called the *solar phosphori*, can never be condensed by any burning-glass, so as to produce the slightest degree of heat. The experiment has also been made with the light of the moon, and that has been found too faint and rare to be condensed into a burning focus.

The principle upon which the rays of light are collected in the focus of a burning-glass will be explained hereafter, when we treat of lenses, and of mirrors. But I do not wish to pass over any thing that I mention, without an attempt to render it clear to your comprehension. I mentioned the *solar phosphori*, of which it is probable that very few of you have heard before. They are certain substances which, when exposed for a little time to the strong rays of the sun, are found to imbibe a large quantity of light, so that they will shine, or appear luminous, if immediately carried into a dark place. The most remarkable of these is the Bolognian phosphorus. It was accidentally discovered by a shoemaker of Bologna. This man had collected together some stones of a shining appearance at the bottom of Mount Peterus, and being in quest of some chemical secret (probably the philosopher's stone, which was to turn every thing into gold), he put them into a crucible to calcine them, or reduce them to the state of a cinder. Having taken them out of the crucible, they were exposed to the light while he was examining them, and afterwards he happened to carry them into a dark place, probably to throw them away; when, to his utter surprise, he observed that they possessed a self-illuminating power. Baldwin, of Misnia, another chemist, observed some time after, that chalk, dissolved in aqua fortis (after the aqua fortis had been evaporated by heat, and the matter reduced to a perfectly dry state), exactly resembled the Bolognian stone in its property of imbibing light, and emitting it after it was brought into the dark, whence it has been termed Baldwin's phosphorus. In truth, the same effect may be produced from calcined oyster-shells, and from all the varieties of that mineral called ponderous spar, of which the Bolognian phosphorus is a species. Diamonds also, and some emeralds, and other precious stones, will emit light when carried out of a light into a dark place. The light emitted by these phosphori always bears an analogy to that which they have imbibed. In general it is reddish; but when a weak light only has been admitted to them, or when it has been received through white paper, the light which they give out is pale or whitish.

III. Notwithstanding the rarity of light, however, and the smallness of its particles, it is not destitute of force or *momentum*. To prove this, a most ingenious experiment was made by the late Mr. Mitchell. He constructed a small vane in the form of a common weathercock, of a very thin plate of copper, about an inch square, and attached to one of the finest harpsichord wires, about ten inches long, and nicely balanced at the other end of the wire by a grain of very small shot. The vane was supported in the manner of the needle in the common mariner's compass, so that it could turn with the greatest ease; and to prevent its being affected by the vibrations of the air, it was enclosed in a glass case, or box. The rays of the sun were thrown upon the broad part of the vane, or copper plate, by a burning-glass of two feet diameter, in consequence of which it was observed to move regularly at the rate of about one inch in a second of time. Upon this experiment a very curious calculation is founded. The instrument or vane weighed about ten grains, and the velocity with which it moved was at the rate of one inch in a second. The quantity of matter therefore contained in the rays of light which struck against the vane in that time amounted to about the twelve hundred millionth part of a grain: the velocity of light exceeding the velocity of the instrument in about that proportion. The light in this experiment was collected from a surface of about three square feet, and as it was from a concave mirror*, only half the quantity was reflected. The quantity of light therefore incident upon a square foot and half of surface is no more than one twelve hundred millionth part of a grain. But the density of the rays of light at the surface of the sun is greater than at the earth, in the proportion of forty-five thousand to one. From one square foot of the sun's surface, therefore, there ought to issue, in the space of one second, one forty thousandth part of a grain of light to supply the consumption. More than two grains a day therefore is, according to

* Mirrors or looking-glasses reflect about half the light that falls on them perpendicularly.

this hypothetical computation, expended from the sun's surface, or six hundred and seventy pounds in six thousand years, which would have shortened his diameter about ten feet, if it were formed of matter of the density of water only. From all this you will conclude that I have adopted the common theory, that *the sun is the great source of light;* and if his diameter is rightly calculated (of which there can be no doubt) at eight hundred and seventy-eight thousand eight hundred and eight miles, we see there is no ground for any apprehensions that the sun will speedily be exhausted by the waste or consump tion of light. The matter will not be widely dif ferent, if we imagine, as is now generally believed, that the particles of light are emitted from a luminous atmosphere which surrounds the body of the sun.

IV. Another principle to which I proposed to call your attention is, that *light always moves in straight lines.* This is evident from an experiment which any person may easily make, viz. that of looking through a bent tube, when no light whatever will be apparent. As a further proof it is only necessary to mention, that when light is intercepted by any intervening body, the shadow is bounded by straight lines.

It is generally supposed, according to this principle, that those bodies only are transparent whose pores are such as to permit the rays of light to pervade them in a rectilinear direction;

and they act like a straight tube, which allows them a free passage; and those bodies are opake whose pores are not straight, and which therefore intercept the rays, like the bent tube already mentioned.

If the rays of light proceed in straight lines, it is obvious that they must be sent from every visible object in all directions. It is however only by those rays which enter the pupil of our eye that they are rendered visible to us; but, being sent in all directions, it is evident that some rays from every part must reach the eye. Thus the object ABC (pl. XI. fig. 46) is rendered visible to an eye in any part, where the rays Aa, Ab, Ac, Ad, Ae, Ba, Bb, Bc, Bd, Be, Ca, Cb, Cc, Cd, Ce, can come; and these affect our sight with the sense of different colours and shades, according to the properties of the body from which the light is reflected, as will be explained when we come to treat of colours.

Of the *refraction* and *reflection* of light I shall hereafter treat more at large; but, in the mean time, it will greatly facilitate the study of optics, if you will carefully peruse, and still more if you will commit to memory, the following principles and definitions.

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

2. The particles of light are *emitted* from what are called *luminous* bodies, such as the sun, a

fire, a torch, or candle, &c. &c.: they are *reflected* or sent back by what are termed *opake* bodies, or those which have no power of affording light in themselves.

3. Light, whether emitted or reflected, always moves in *straight* or *direct lines;* as may easily be proved by looking into a bent tube, which evidently obstructs the progress of the light in direct lines; and proves that the theory of rectilinear emission is free from the objections which lie against the hypothesis of the undulatory motion of light.

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

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

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

7. *Diverging rays* are those which, proceed-

ing from a point, continue to recede from each other, and exhibit the form of an inverted cone.

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

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

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

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

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

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

14. The *angle of incidence* is the angle which is formed by the line which the incident ray

describes in its progress, and a line drawn perpendicularly to the reflecting surface; and the *angle* of *reflection* is the angle formed by the same perpendicular and the reflected ray. Thus, in fig. 47, AB is the reflecting surface, CG is a line drawn perpendicularly to that surface, *e* is a ray of light incident at G, and reflected to *f*; and the angle CG*e* of incidence is evidently equal to the angle CG*f* of reflection.

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

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

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

tion disperse the rays of light, and diminish the objects that are seen through them. The varieties of these will be described in a subsequent lecture.

18. *Vision* is performed by a contrivance of this kind. The crystalline humour, which is seated in the fore part of the human eye, immediately behind the pupil, is a perfect convex lens. As therefore every object is rendered visible by beams or pencils of light which proceed or diverge from every radiant point of the object, the crystalline lens collects all these divergent rays, and causes them to converge on the back part of the eye, where the retina or optic nerve is spread out; and the points where each pencil of rays is made to converge on the retina, are exactly correspondent to the points of the object from which they proceed. As, however, from the great degree of convergence which this contrivance will produce, the pencils of light proceeding from the extreme points of the object will be made to cross each other before they reach the retina, the image on the retina is always inverted.

19. The magnitude of the image painted on the retina will, therefore, it is evident, depend on the greatness or obtuseness of the angle under which the rays proceeding from the extreme points of the object enter the eye. For it is plain, that the more open or obtuse the angle is, the greater is the tendency of these rays to meet

in a point and cross each other: and the sooner they cross each other, after passing the crystalline lens, the larger will be the inverted image painted on the retina. The *visual* angle, therefore, is that which is made by two right lines drawn from the extreme points of any object to the eye; and on the measure of that angle the apparent magnitude of every visible object will depend.

20. The *prism* used by opticians is a piece of fine glass, in form of a geometrical triangular prism; it has the power of separating the rays of light.

LECTURE XI.

EXPERIMENTAL PHILOSOPHY.

THE REFRANGIBILITY OF LIGHT.

THE natural progress of light, we have already seen, is in straight lines; yet it is found to be subject to the laws of attraction, as well as all other bodies; and, under the impulse of that power, it is sometimes turned out of its direct course. This only happens when it passes out of one medium into another of a different density, as from air into water or glass, or from water or glass into air; and this property of light is called *refraction*. A very easy experiment will show you what is meant by refraction; for, if you put one end of a straight stick into water, it will appear at the surface as if it were broken, that is, *refracted*, from the Latin verb *refrango*, to break.

It is evident that this effect can only arise from the rays of light being drawn or attracted out of their direct course; and this I shall prove by a very common and a very easy experiment. Put a shilling, or any other conspicuous but small object, into a bason or other vessel, and then retire to such a distance, as that the edge of the vessel shall just hide it from your sight. If, then, you remain motionless while the vessel is filled with water, you will find that the shilling will be rendered perfectly visible, though in fact neither you nor it have changed places in the slightest degree.

Let it be remembered, that it is only the *rays which fall obliquely that are thus refracted;* for a ray which falls perpendicularly is equally attracted on all sides, and therefore suffers no refraction at all. To illustrate this by the experiment which has just been mentioned. You must know that it is by light reflected from it to your eye that any object is rendered visible: you see the shilling in the bason, therefore, by rays of light which are reflected from its surface. Now the angle of incidence and the angle of reflection are equal; and as you stand in an oblique direction to the shilling, you see it, while the bason is empty, by rays of light which fall upon it in a direction exactly as oblique as that in which your eye is situated towards it. The shilling, then, which before was hid from your sight, is rendered visible by pouring in the water, because the rays of light, which serve to render it then visible, are bent out of their course. Thus the ray of light, AC, pl. XII. (fig. 48), which passes obliquely from the air into water at C, instead of continuing its course to B, takes the direction *Ca*, and consequently an object at *a* would be rendered visible by rays proceeding in that direction, when they would not have touched it, had they proceeded in their direct course.

By this figure you will understand that the angle of refraction PC*a* is not so large as the angle of incidence *p*CA, but bears a certain proportion to it; and this proportion or ratio varies with respect to different mediums. Thus, when a ray passes from air into water, the angle of incidence is to that of refraction in the ratio of about four to three; from air into glass nearly as three to two; from air into diamond nearly as five to two; and the contrary proportion holds in passing back again; as when light passes from water into air, the ratio is as three to four, &c. From all this you will clearly understand, that the more obliquely a ray falls, the greater is the refraction. It is also necessary that you should remember, that light is refracted or drawn towards the perpendicular, (as in fig. 48), when it passes out of a rare into a denser medium; and it is refracted from the perpendicular, or in a more oblique direction, when it passes from a dense medium into one which is rare; and the denser the medium, the greater is the refraction: thus the diamond is found to refract most powerfully.

This principle will explain several of the common phænomena of nature. Mr. Walker observes, that "many a school-boy has lost his life by supposing the bottom of a clear river to be within his depth, as (when he stands on the bank) the bottom will appear one-fourth nearer the surface than it really is." In this case, the rays proceeding out of the denser medium (the water) into the rarer (the air), they are bent out of their course more obliquely towards the eye of the spectator. Have you ever seen a skilful marksman shoot a fish in the water with a bullet? If you have, the sportsman could tell you that he took his aim considerably (perhaps a foot) below the fish as it appeared, because it seemed much nearer the top of the water than it really was. The distortion of objects through a wrinkled or crooked pane of glass, arises also from the unequal refraction of the rays that pass through it. When light passes out of pure space into air, it is also refracted; and therefore the sun is visible, by means of the refraction of our atmosphere, some minutes before he rises above the horizon in the morning, and some minutes after he sets below it in the evening. It has been calculated that, in looking through the common glass of a window, objects appear about one-thirtieth part of an inch out of their real place by means of the refraction.

But the most excellent use to which this principle has been applied is the construction of optical glasses; for, by grinding the glass thinner at the edges than in the middle, those rays of light, which would strike upon it in a straight line, or perpendicularly if it were plain, strike upon it obliquely, and consequently suffer a refraction, and are made to converge; and, on the contrary, by making the glass thinner in the middle than at the sides, the rays are refracted the contrary way, and are made to diverge.

The reason of this will be sufficiently evident, if it be recollected that all curves or segments of a circle may be conceived as formed of a number of straight lines infinitely short, and inclining to each other like the stones in the arch of a bridge, or the bricks at the top of an arched window-frame. It is evident, therefore, that in fig. 49, where parallel rays are supposed to strike a surface of this form, those only which enter the middle part will go in a straight direction, whereas those which strike the sides will strike them obliquely, and will consequently be refracted. If the surface, then, be a perfect curve, as in fig. 50, it is plain that only the ray which strikes the centre point of the curve will enter it in a straight direction, and consequently all the rest which strike it obliquely will be more or less refracted, according to the degree of obliquity, and will consequently be made to converge.

Glasses are usually ground for optical purposes into seven different shapes (see fig. 51). First, the glass may be flat on both sides, as the common pane of a window, No. 1. Or, secondly, it may be flat on one side and convex on the other, *plano-convex*, No. 2. Or, thirdly, it may be convex on both sides, like our ordinary reading-glasses, No. 3. Or, fourthly, it may be flat on one side and concave on the other, *plano-concave*, as No. 4. Fifthly, it may be concave on both sides, like the glasses near-sighted people generally use, as No. 5. Sixthly, it may be concave on one side and convex on the other, like the crystal of a watch, though not in such a degree, as No. 6; this is usually called a *meniscus.* Seventhly, it may have one side, which must be convex, ground into little facets, like those of some jewels, while the other side is plain. Children know it by the name of a *multiplying-glass*, as No. 7.

The effects of these different glasses will be easily understood from what has been premised. A ray entering the plain glass, No. 1, will indeed be refracted by the glass, but it will suffer another refraction on going out of it, which will nearly rectify the former; the place of the object will, therefore, as was before stated, be a little changed, but its figure will remain unaltered.

If, again, several parallel rays enter the glass, No. 2, plain on one side and convex on the other, as in figure 50, they will be differently refracted, in proportion to the obliquity with which each of them falls upon the surface. The middle ray, for instance, which passes perpendicularly through, will not be refracted at all, but go on straight forward. All the other rays, however, will suffer refraction. The ray CE, fig. 50, will be refracted upwards to F; the ray A D will be refracted downwards to the same point. There they will cross, and then go onward, diverging or separating from each other for ever; that which came from the bottom going upward, and that which came from the top downward. The figure given there is flat, but it must be supposed spherical, the glass being represented edgeways. If so, therefore, the collected bundle of rays, passing through the glass, unite and form a cone, or a figure like a candle extinguisher, the bottom of which is at the glass, and the point at F. This point, as I once before had occasion to mention, is called the focus of the glass. From a calculation in geometry, we learn that the distance from this point is always equal to the diameter of the circle which the glass would make if its convexity were continued.

When the rays of the sun fall directly upon a glass DE, (see fig. 52) equally convex on both sides, they will be refracted still more abruptly, and meet sooner in a point or principal focus at *f*. The distance of this focus is, we are informed by the same calculation, equal to the semi-diameter of the circle, which the convexity of the glass continued would make. Either this glass or the former, as they collect the rays of the sun into a point, will burn at that point, since the whole force of the rays is concentrated there. The broader the glass in these instruments, the greater will be its power, from its collecting a greater number of rays.

It is to be observed, that they are only parallel rays, or those which proceed in a direct line to the surface of the glass, that are thus converged to a point or focus; the rays of the sun, however, come from so great a distance, that they are always regarded as parallel. Divergent rays, such as proceed from a point, as the flame of a candle, will be refracted parallel. If, therefore, we place a candle exactly at a focal distance from one or both of these glasses, as at *f*, its rays will, upon going through the glass, all run parallel to each other. If the candle is placed nearer the glass than its focal distance, the rays, after passing through the glass, will no longer run parallel, but separate or diverge: if it is placed farther off, the rays will then strike the glass more parallel, and will therefore, upon passing through it, converge or unite at some distance behind the glass.

After the rays have united or converged to a focus, they will cross each other, and form an inverted picture of the flame of the candle, as may be seen on a paper placed at the meeting of the rays behind. How the image is inverted, therefore, is easy to apprehend; for the upper rays, after refraction, were such as came from the under part of the luminous body; and the under rays, on the contrary, came from its top: so that the rays are turned upside-down, and so consequently is the image. It is very pleasing to view a picture of this kind thus formed, each ray preserving the colour it had in the luminous object with the utmost imitative precision. The shadings of the little piece are far beyond the reach of art, and the design far more correct than that of the finest painter. I mention the candle as being an obvious luminary; but if any object whatever is placed at the proper distance from a convex glass, its picture will be, in the same manner, thrown behind, and may be received upon paper, or any other body, in all its natural proportions and colourings. The nearer the natural object is to the refracting glass, the farther off will this picture be behind it; because, as was said before, the rays which form it do not then converge or unite, but at a great focal distance. The farther off the natural object is, the nearer will be the focal distance it makes, and consequently the nearer will be the picture behind the glass; for, wherever the focus is, there will the perfect picture be. When however the rays come from several objects at a moderate distance, they may be considered as all parallel, and this difference of focus is then imperceptible.

To put what has been said in other words.—As the rays of the sun may be all considered as falling parallel upon every glass of the convex kind, so they must always unite behind it in a focal point. As all the rays flowing from other objects are not always parallel, when placed too near the glass, they separate after refraction, and run off divergent; when placed at a proper distance, they unite or converge in a focal point, and there imprint a picture, if there is any thing properly placed to receive it, in which the natural figure will be represented, its motions, its colours and shadings.

The whole of the preceding theory may be illustrated by means of a common reading-glass. If a candle is held so near it, as that the rays passing through shall strike the wainscot of the chamber with a bright spot, just as large as the glass itself, the candle is then at the focal distance; and rays, striking the glass divergently, are refracted through it, parallel to each other, neither spreading nor drawing together as they proceed. If the candle is held nearer than the focal distance, the rays will fall then more divergent upon the glass, and will consequently be refracted more divergent, so that they will form a very broad spot of light upon the wainscot. If the candle is placed at a much greater distance than the focus, the rays fall upon the glass more nearly parallel, and consequently, when they are refracted will tend to unite and converge behind the glass, and will form but a small speck of vivid light on the wainscot. This speck, if closely examined, will appear a perfect picture of the candle.

Every visible point, in any body whatever, may be considered as a candle sending forth its rays, which split and *pencil* out into several other rays before they arrive at the eye. Each body is as if composed of an infinite number of splendid points or candles, each point with its own radiance, and diffusing itself on every side. Instead of one body, the eye, in fact, is impressed with thousands of radiant points sent out from that body, which being grouped at the bottom of the eye, imprint the picture of the object whence they flow. Each point sends forth its own rays.

It is upon this principle the camera obscura is constructed. If we take a double convex glass and adapt it so as to fit a hole in the window-shutter of a darkened chamber, so that no light shall come into the room but through the glass; then let us place a sheet of white paper behind it at the proper distance, we shall thus have a camera obscura; for a picture of every external object will pass through the glass, and be painted upon the paper in the most beautiful colours that imagination can conceive, and all the motions of those objects also. It is necessary, in this experiment, that the window should not be opposite to the sun; for then we should see no image but that of his brightness: and yet it is necessary also, that while we make the experiment, the sun should shine and illuminate the objects strongly, which are to paint themselves within. Without this strong illumination, the rays will be sent so feebly from every object, that we shall have but a faint picture, if any at all.

Painters and architects often make use of a similar contrivance, or portable camera obscura, to take a draught of landscapes or buildings: their glass is fixed in a box, and by means of a mirror, on which the diminished pictures fall, they are reflected upon oiled paper or polished glass properly placed, upon which the artist sketches his draught. With regard to the contours, or outlines, which this picture gives, nothing can be more exact; but, so far as respects the shading and colouring, the artist can expect but little assistance from it: for, as the sun is every moment altering its situation, so is the landscape every moment varying its shade; and so swift is this succession of new shades, that, while the painter is copying one part of a shade, the other part is lost, and a new shade is thrown upon some other object.

If such a glass, that is, double convex, is so fitted to a hole in a dark lantern, that little pictures, painted in transparent colours on pieces of glass, may be passed successively along between the glass and the candle in the lantern, we shall thus have a magic lantern. The pictures, striking the glass very divergent, will be refracted very divergent also, and will be painted upon the wall of the chamber in all their colours, as large as we please to make them; for the farther the wall is from the glass, the more room will the rays have to diverge. As these figures would be painted on the wall reversed, if the picture were held upright, it is necessary to turn them upside down, when we would exhibit the shadows on the wall erect. The same kind of contrivance is now employed, with great success, to elucidate the principal phænomena of astronomy.

In looking through a glass of this description, that is, a convex or double convex lens, the objects which we look at will appear magnified; for it is a rule in optics, *that we see every thing in the direction of that line in which the rays approach us last.* When I come to treat of the eye, the reason of this will be explained. Suffice it to say for the present, that the larger the angle under which any object is seen, the larger will any object appear. The convergence of the rays of the convex lens, therefore, enlarges greatly the angle of vision, as must be evident if we continue the lines fD, fE, fF, and fG, fig. 52, in the direction to which they point, and therefore in proportion to the distance the appearance of the objects will be enlarged. The common spectacle-glasses and reading-glasses are of this description.

The effects of the plano-concave and double concave lenses, No. 4 and 5, are directly opposite to those of the convex lenses; for the thick parts of these glasses, you see, are towards the edge, and therefore their attractive and refractive powers are not towards the centre, but towards the circumference. Parallel rays, therefore, striking one of these glasses are made to diverge, or are dispersed. Rays already divergent are rendered more so; and convergent rays are made less convergent. Hence objects seen through these glasses appear considerably smaller than they really are. To prove this, let *ab* (fig. 53) represent an arrow, which would be seen by the eye, if no glass were between, by the convergent rays, *ca* and *db*; but if the concave lens D be interposed between the object and the eye, the line *ac* will be bent towards *g*, and the line *bd* will be bent towards *k*, and consequently both will be useless, as they do not enter the eye. The object then will be seen by other lines, such as *ao* and *br*, which, on entering the glass, will be refracted, and bent in the directions *oc* and *rd*. According to the rule just now laid down, therefore, every object is seen along the line which enters the eye last. The arrow is seen according to the angle *or*, which is much smaller than the angle *ab*; consequently it will appear considerably diminished, and at the distance of *nm*.

The spectacles which are used by near or short-sighted persons consist of concave lenses; for the reason of short sight is, that, the form of the eye being too convex, the rays are made to converge before they reach the optic nerve; and therefore the concave glass, causing a little divergence, assists this defect of sight. But this matter will be still further explained when we treat of vision.

The meniscus, No. 6, is properly like the crystal of a common watch, and it neither magnifies nor diminishes. Sometimes, however, it is made in the form of a crescent; that is, thickest in the middle; and in that case it acts like a double convex lens.

It is evident that all lenses, as to their surfaces, whether concave or convex, are segments of different circles, the radii and diameters of which may vary almost to an infinite extent. The distance of the principal focus, or focus of parallel rays, that is, the point where all the parallel rays meet, as the point *f*, fig. 52, will vary in different lenses, according to their respective degrees of convexity. Hence, when opticians speak of the radius of a lens, when they say it is three or six inches, they mean that the convex surface of the glass is that part of a circle, the radius (that is, half the diameter) of which is three or six inches. The axis of a lens is a straight line drawn through the centre of its spherical surface.

The principal focus, or focus of parallel rays, in convex lenses, is ascertained (as was before intimated) upon mathematical principles. It may however be found with sufficient accuracy for common purposes, by holding a sheet of paper behind the glass, when exposed to the rays of the sun, and observing when the luminous spot is smallest, and when the paper begins to burn. Or when the focal length does not exceed three feet, it may be found by holding the glass at such a distance from the wall opposite a window sash, as that the sash may appear distinct upon the wall.

You will observe, that in a double convex lens the rays of light are twice refracted; first, on entering the convex surface of the dense medium, the glass; and, secondly, on going out of the same dense medium, and entering the rare medium, or the air, which, from the form of the glass, you know must present a concave surface. Now rays are equally converged by entering a convex surface of a dense medium, and a concave surface of a rarer medium. The focus of a double convex lens, then, is at only half the distance of the focus of one which has only one convex surface, that is, a plano-convex. The focus of a double convex lens, therefore, as you have already seen, fig. 52, is the length of the radius, or semi-diameter of that circle, which is formed by the convexity of either of its surfaces.

That branch of optics which respects the refrangibility of light is usually called dioptrics, from the Greek *dia*, through, and *optomai*, to see; so that it means to see through.

LECTURE XII.

EXPERIMENTAL PHILOSOPHY.

REFLEXIBILITY OF LIGHT, OR CATOPTRICS.

THERE is no part of the science of optics more amusing, or indeed more astonishing, to unscientific readers, than that which regards the reflection of light. How a looking-glass comes to reflect images without their touching it; how the whole figure of a man, six feet high, shall be seen in a glass not above three feet; how, when we look at some polished surfaces, as a watch-case, for instance, a man's face seems not bigger than his finger-nail; while, if we look on other surfaces, the face shall be of gigantic size; these are all wonders that the curious would wish to understand, and the inexperienced to examine.

The property which polished surfaces possess of reflecting light, is referred by Newton to the principle of repulsion. For it is justly remarked by him, that those surfaces, which to our senses appear smooth and polished, are found, when viewed through a microscope, to be still rough and uneven. It will, however, suffice for our purpose, in describing the effects of reflection, if we consider every particle of light as rebounding from the surface of a mirror, like a tennis-ball from the wall of a tennis-court.

It is, in truth, by reflection that all objects are rendered visible. Even glass, crystal, and water reflect a part of the rays of light, or their forms and substance could not be distinguished; but those bodies which transmit it copiously, are called clear or transparent; those which do not transmit it, are termed *opake*. The whole of the light which falls upon bodies, is not, however, reflected. On the contrary, it is calculated that the smoothest and most polished surfaces do not reflect above half the light that falls upon them. Those bodies with polished surfaces, which reflect most copiously the rays of light, are called *mirrors;* by the ancients they were made of metal, as iron, tin, or copper, and exquisitely polished; those in general use among us are made of glass, rendered opake at the back part by an amalgam or mixture of tin and quicksilver, or mercury. Mirrors are made in various forms; *plane*, that is, with a smooth and level surface; *convex*, *concave*, or *cylindrical.* The most common are the plane mirrors.

A ray of light striking perpendicularly, in a direct line, upon a plane mirror, is reflected in exactly the same direction. Those rays which strike it obliquely, are reflected back in an opposite direction, but with exactly the same degree of obliquity. Hence the great law of reflection is, that *the angle of reflection is exactly equal to the angle of incidence.* This was explained to you in the tenth lecture, fig. 47, and it will serve to elucidate all the phænomena of reflection.

Lest you should, however, have attended to the maxims and definitions subjoined to that lecture less assiduously than you ought, I shall refer you to another figure. In Pl. XIII. fig. 54, *no* may be considered as a ray of light striking perpendicularly on the surface of the mirror *a b*, and it is consequently reflected back in the same line. The ray *d o*, coming from the luminous body *d*, strikes the mirror obliquely, and is reflected to the eye in the line *o e*, in such manner, that the angle *e o n* is equal to the angle *o d n*; in other words, the angle of reflection is equal to the angle of incidence.

This, you will answer, is sufficiently clear; but how comes it that I do not see the object at *o*, since it is there that the rays strike the mirror? And why is it, that, on the contrary, the object appears behind the glass, and in the situation of *s*? This has been partly explained by a rule which I formerly laid down; namely, that we *see every thing in that line in which the rays last approached us*. Now an object is rendered visible, not by single rays proceeding from every point of its surface, but by pencils of rays, or collections of divergent rays issuing from every point, as was explained in the preceding lecture. These pencils of rays are afterwards, by the refractive powers of the eye, converged again to points upon the optic nerve, which lies at the back of the eye; and these points of convergent rays on the optic nerve, are correspondent to the points of the objects from which the rays diverged. Now the pencils of rays strike the mirror, while they are in their divergent state; and as the angle of reflection is equal to the angle of incidence, they are reflected back in the same state, and converge exactly as they would have done had they not been intercepted by the mirror. As, therefore, we always see objects in the line in which the rays approached us last, the two lines, viz. that which goes from the object towards the mirror, and the reflected line, are united in the mind of the spectator, and the object is consequently seen at *s*, at an equal distance behind the mirror, as the object was before it. To make this clear, however, I shall present you with another diagram. The lines D *c*, (fig. 55.) are the lines of incidence, *c* B are the lines of reflection, and these form equal angles on the surface of the polished mirror; so that all the rays coming from the object, and falling upon the mirror at *c*, will strike the eye at B, and the reflected image will thus become visible. Now no object can be seen that does not lie in a straight line from the eye, or, at least, appear to do so. The body D, therefore, when it comes reflected to the eye, will appear to lie in the straight line AA, which, since the angle of incidence is equal to that of reflection, will be exactly in the two lines D *c* and *c* B. The rays, therefore, going from D to *c*, will seem to have proceeded to A, and consequently the picture will be there. For, as the rays have diverged in going from the object at DD, and diffused themselves upon the surface of the glass, they will be again converged into an equal focus, by the time they arrive at B *b*, and they will therefore paint the object at AA.

Hence we may learn, that if a man sees his whole image in a plane looking glass, the part of the glass that reflects his image, need be but one-half as long, and one half as broad as the man. For the image is seen under an angle, as large as the life; the reflecting mirror is exactly half-way between the image and the eye, and therefore need be but half as large as the object, to subtend an angle as large as the image; or, in other words, it is just half as large as the image, which is of the same size with the man. Thus the man AB, (see fig. 56) will see the whole of his own image in the glass CD, which is but half as large as himself. His eye, at A, will see the eye of the image at an equal distance behind the glass at E. His foot at B, will send its rays to D; these will be reflected at an equal angle, and the ray will therefore seem to have proceeded in the direction of FDA, so that the man will see his foot at F; that is, he will see his whole figure at EF.

It is thus that plane mirrors reflect. The nature of those which are convex or concave is a more difficult study, though the same law prevails with respect to them as with respect to the others. To understand the principles on which they act, it will be expedient to call to your recollection what was said in the former lecture on spherical surfaces. All curves or arches may be considered as composed of a number of small flat planes, lying obliquely to one another. Parallel rays, therefore, striking an object opposed to them in this position, will strike it more or less obliquely. Thus, in fig. 57, the rays *a, b, c, d,* which would fall perpendicularly on a horizontal surface, strike obliquely upon those which are opposed to them; and, instead of being reflected parallel, are reflected divergent. For the same reason, convergent rays would be reflected less convergent by such a mixed surface as this, and divergent rays would be rendered still more divergent. Fig. 58, you see, is the reverse of the preceding, and it serves very well to represent the effects of a concave mirror. By this you must perceive that the parallel rays *a, b, c, d,* which would have been reflected parallel by a plane mirror, are made to converge, because, instead of striking this mirror in a direct line, they strike it obliquely; and you may easily conceive, that by the same rule, convergent rays will be reflected still more convergent, and divergent rays will be made to converge less.

As by a mirror of the convex kind convergent rays are rendered less convergent, you will easily comprehend why objects are diminished by it. By the rays being made less convergent, the visual angle is diminished; for, you know, we see every object in the line in which the rays of light last approached the eye. By the same rule, a concave mirror magnifies or enlarges the image of an object; for the visual angle is enlarged or rendered more obtuse, and consequently the image is magnified in proportion to the curvature of the concave surface.

To prove what I have just now laid down with respect to convex mirrors, in fig. 59, *a b* is a dart, which is seen in the convex mirror *c d*. Now, though rays issue from the object *a b* in all directions, as was explained in the tenth lecture, Plate XI. fig. 46, yet it is seen only by means of those which are included within the space between *o* and *n*, because it is only those which can be reflected to the eye at *r*. Now you will easily perceive that if these rays had gone forward in the direction in which they were proceeding, they would have united at *p*, and the object would have been seen of its full size. As it is, however, the rays are reflected less convergent than they were in their natural course, and the angle *o r n*, being less than the angle *a p b*, the image at *s* appears smaller than the object, and nearer to the surface of the mirror. The reason of this last effect has been already explained, when I said that objects are rendered visible, not by a single ray, but by pencils of divergent rays proceeding from every point of the object. Suppose, therefore, G (fig. 60) a radiant point of any object, from which a pencil of divergent rays proceeds, and falls on the convex mirror *a b*. These rays (agreeably to the rule laid down above, that convex mirrors cause divergent rays to diverge still more) will be rendered more divergent, and will have their virtual or imaginary focus at *g*, that is, much nearer to the surface of the mirror than if it were plane.

For these reasons, a person looking at his face in a convex mirror, will see it diminished. Thus, in fig. 61, though rays proceed from every part of the face, it is only the rays that touch the mirror within the space between *c* and *r* that can, agreeably to the great law of reflection, (the angle of incidence being equal to the angle of reflection) be reflected to the eye. The rays *c* and *r* being therefore rendered less convergent (as in the former instance in fig. 59), he will see the chin along the line *o r s*, and the forehead along the line *o c n*, and the angle of vision being thus diminished, all the rest of the features will be proportionably reduced. Large objects, however, placed near a convex mirror, will not only appear reduced, but distorted; because, from the form of the glass, one part of the object is nearer to it than another, and consequently will be reflected under a different angle.

Convex mirrors are at present a very fashionable part of modern furniture, as they exhibit a large company, assembled in a room, in a very small compass. Globes lined with amalgam used to be formerly hung up in the middle of a room, by which the whole company were exhibited at one view, seated at a dinner-table, or dispersed about the room.

The phænomena of concave mirrors are still different. By them convergent rays are rendered still more convergent, and consequently the visual angle is enlarged. Their general effect is therefore to magnify. This will be sufficiently exemplified by PL. XIV. fig. 62. In this, as in the former instance, a face is looking at itself; and I take the extreme of those rays which can be reflected to the eye, one from the forehead and one from the chin. These lines, $a\,c$, and $m\,n$, are reflected to the eye at o, which consequently sees the image in the lines of reflection, and in the angle $o\,d\,q$, and therefore evidently magnified beyond the natural size, and at a small distance behind the mirror.

This effect, however, will only take place when the eye is between the mirror and its principal *focus*, that is, the focus or point, where rays falling parallel or perpendicular on the glass, will unite after reflection; the point where the rays of the sun (which are always considered as parallel) will unite and burn: for a concave mirror acts as a burning-glass. By the great law of reflection, the principal focus of a concave mirror, is at one-fourth of the diameter of that sphere, of which the concave surface is a section, which is therefore sometimes called the centre of concavity. At this point the rays reflected from the mirror, are converged and cross; and if the spectator's eye is beyond this point or focus, he will not see the image behind the mirror, but before it, a shadowy form, suspended in the air; but, from the crossing of the rays, it appears inverted.

In fig. 63, *a b* is a concave mirror, *c d* is a hand held up before it. The image, therefore, you see is not placed behind the mirror, as happens in every other case, but the hand seems to hang suspended in the air at *m*. The reason of this very extraordinary and striking phænomenon is to be found in what was already intimated. Objects are rendered visible, not by single rays, but by pencils of divergent rays, proceeding from the different points of the object. If these pencils of divergent rays should happen by any cause to be united, the object will in that point cease to be visible. This happens in the focus of a concave mirror, where, by the law of reflection, they are all united. If the eye, therefore, is placed in that point, it will see nothing of the image. It must recede to a sufficient distance to permit the rays to cross and again become divergent. In that case the image will be seen, not behind the mirror at the virtual or imaginary focus, as it is in plane and convex mirrors, but suspended in the air between the eye and the real focus, for every image is seen about that place, whence the pencils of rays begin to diverge. In plane mirrors the rays have only diverged from the luminous points of the object itself; and as the eye cannot see behind, it sees the image in a straight line, but joins the line of incidence and that of reflection together. The image therefore appears at the same distance behind the glass, as the object stands before it. In concave mirrors the case is entirely different; for in them there is an actual focus, where the rays are converged to a point, and from which they begin again to diverge. The image is therefore seen there, but in an inverted position, for reasons already given. Thus, in fig. 63, the rays *c* and *d* go diverging from the two opposite points of the object; by the action of the mirror they are again made to converge to a point at *o s*, where they cross, and again proceed divergent to the eye.

It will, however, render this interesting part of optics still clearer, if I present you with another diagram, similar in some degree to the preceding. In fig. 64, A*c*B is a concave mirror. The centre of concavity is at C. From the points of the dart D, we suppose a pencil of divergent rays emitted, which you see touch the mirror at A*c*B. These rays are reflected, according to the general law of reflection, (the angle of reflection being equal to the angle of incidence) which is proved by drawing the dotted lines CA, C*c*, CB, from the centre of concavity to the points whence these rays are reflected, which are therefore perpendiculars to the surface of the mirror. The angle CA*d*, or the angle of reflection, you see, is equal to DAC, the angle of incidence, and so you will find it of the rest. The reflected rays then, you see, converge to a point, and form the extremity of the dart (which is now inverted) at *d*. In the same manner every other pencil of rays emitted from the object, will be converged at or near the principal focus, and the image will be formed at *e d*. For you will perceive that if the rays E*f*, E*g*, E*h*, were continued to the mirror, they would be reflected and converged at *e*, forming the opposite extremity of the dart. When the object is further from the mirror than the centre of concavity C, the image will be nearer the mirror, and smaller than the object; when the object is nearer than the centre of concavity, the image will then be more remote, and larger. Thus, if *e d* was the object, DE would be the reflected image.

It is not many years since a person derived considerable emolument from exhibiting in the metropolis some optical deceptions of this kind, with concave mirrors. A ghastly apparition was sometimes made to meet the ignorant spectator, and from its shadowy appearance it was evidently nothing human; sometimes a hand was held out in the air, with every possible mark of friendship, but when he approached to unite it with his own, a drawn sword was instantly presented to his breast. A nosegay, or a piece of fruit was offered, but when he attempted to seize it, a death's head snapped at him.

I mentioned that concave mirrors were frequently used as burning-glasses, and a curious experiment may be made by means of them, to show that common culinary fire may be reflected in the same manner as the rays of the sun. If two large concave mirrors are placed opposite to each other, as in fig. 65, at almost any distance, and a red-hot charcoal is held in the focus of one at *a*, and a match, or any combustible matter, in the focus of the other at *b*, the match, &c. will be presently set on fire by the reflected flame of the charcoal.

You have seen, I dare say, the distorted figures which are sometimes painted on boards, and exhibited in the shop-windows of opticians. They look like a mere splash of a painter's brush; but when a mirror of a cylindrical or conical form is set in the middle of the board, a beautiful figure is reflected from it. This shows that what appears to be a casual dash of paint on the board is, in fact, a figure drawn with the nicest mathematical precision. When the image is to be rectified by a cylindrical mirror, the lines are only extended, and, by the great law of reflection, the rays from the picture are reflected by the mirror less convergent, and the figure is consequently rectified. A little consideration on this subject, applying the principles which have been laid down in the course of this lecture, will easily enable you to see the theory on which these mirrors act, particularly if you have the objects before you: without which, indeed, an infinity of words must be expended in describing and explaining them.

LECTURE XIII.

EXPERIMENTAL PHILOSOPHY.

VISION AND OPTICAL GLASSES.

It has already been explained, that objects are rendered visible not by single rays, but by small bundles of rays diverging from every point of the object, like an inverted cone, or like a painter's brush or pencil, and therefore called pencils of light. It has also been intimated, that these pencils of light are, by the refractive powers of the eye, again made to converge upon the back part of that organ, in points corresponding to those from which they proceeded, so as to form there a complete image of the object. In the tenth lecture, fig. 46, it was further shown, that pencils of light are sent forth in all directions, from every part of a visible object; so that an eye, when placed in any situation that light can travel to it from the object in a straight line, (whether above or below, or at either side) shall be able to perceive it.

In describing the nature of refraction, enough has been said to show you that it is the property of every convex glass to cause the rays of light to converge. In this respect the eye is to be considered as a convex lens, constructed with such admirable skill by the great Author of Nature, that the rays converge to a point exactly in the proper place; so that if the humours were otherwise disposed, even to the breadth of a horse-hair, the effect would be totally destroyed. But you will understand the subject better, by considering the structure of this curious organ; in describing which, I shall adopt the simple, but expressive language of Mr. Ferguson.

The eye is nearly of a globular form. It consists of three coats and three humours. (See fig. 66.) The part DHHG of the outer coat is called the *sclerotica;* the rest, D E F G, the *cornea.* Next within this coat, is the *choroides,* which serves for a lining to the other, and joins with the *iris mn, mn.* The *iris* is that coloured circle which gives the character, as to colour, to the eye, and is composed of two sets of muscular fibres; the one of a circular form, which contracts the hole in the middle, called the *pupil,* when the light would otherwise be too strong for the eye; and the other of radial fibres, tending every where, from the circumference of the iris, towards the middle of the pupil; which fibres, by their contraction, dilate and enlarge the pupil when the light is weak, in order to let in more of its rays. The third coat is only a fine expansion of the optic nerve L, which spreads like net-work all over the inside of the choroides, and is therefore called the *retina;* upon which are painted the images of all visible objects, by the rays of light which either flow or are reflected from them.

Under the *cornea* is a fine transparent fluid, like water, which is therefore called the *aqueous humour*. It gives a protuberant figure to the cornea, fills the two cavities *mm* and *nn*, which communicate by the pupil P, and has the same refractive power as water. At the back of this lies the *crystalline humour* R, which is shaped like a double convex glass, and is a little more convex on the back than the forepart. It converges the rays, which pass through it from every visible object, to its focus at the bottom of the eye. This humour is transparent, like crystal, and is much of the consistence of hard jelly. It is inclosed in a fine transparent membrane, from which issue radial fibres, called the *ligamentum ciliare,* all around its edge; and join to the circumference of the iris. These fibres have a power of contracting and dilating occasionally, by which means they alter the shape or convexity of the crystalline humour, and also shift it a little backwards or forwards in the eye, so as to adapt its focal distance at the bottom of the eye, to the different distances of objects; without which provision, we could only see those objects distinctly, that were all at one distance from the eye.

At the back of the crystalline lies the *vitreous humour* KK, which is transparent like glass, and is the largest of all in quantity, filling the whole orb of the eye, and giving it a globular shape. It is much of the same consistence as the white of an egg, and very little exceeds water in its refractive power.

As every point of an object ABC, sends out pencils of rays in all directions, some rays, from every point on the side next the eye, will fall upon the cornea between E and F; and by passing on through the humours and pupil of the eye, they will be converged to as many points on the retina or bottom of the eye, and will there form a distinct inverted picture *cba* of the object. Thus, the pencil of rays *qrs*, that flows from the point A of the object, will be converged to the point *a* on the retina; those from the point B will be converged to the point *b*; those from the point C will be converged to the point *c*; and so on of all the intermediate points: by which means the whole image *abc* is formed, and the object made visible.

That vision is effected in this manner, may be demonstrated experimentally. Take a bullock's eye while it is fresh, and having cut off the coats from the back part, quite to the vitreous humour, put a piece of white paper over that part, and hold the eye towards any bright object, and you will see an inverted picture of the object upon the paper.

It has been a matter of inquiry among scientific persons, why the object appears in an upright position, while the image on the retina is inverted. In truth, we know nothing of the connexion which exists between the thinking faculty and the organs of sensation. It may, however, suffice to answer the present question, if we say that the mind certainly does not look upon the image which is painted on the optic nerve. That nerve is sensible of the impression, from the rays of light being reflected upon it, as the organs of touch feel the impression of any external object, by coming in contact with it. Nor is there any reason why the mind should not perceive as accurately the position of bodies, if the rays reflected from the upper parts of those bodies are made to touch the lower parts of the eye, as if they had been directed to the upper parts. Suffice it, that such a correspondence is established between the parts of the eye to which the rays are converged, and the different parts of the object, that we do not find that persons blind from infancy, who have been restored to sight by the operation of couching, have been led into the smallest mistake as to this point*.

To very perfect sight the three humours of the eye appear necessary. Yet by a very bold experiment (for such it undoubtedly was at first), it is found that we can see tolerably well, even though one of them should be taken away, par-

* For an elaborate disquisition on this subject, the reader may consult the Rev. A. Horn's Essay on Vision.

ticularly if we assist the sight by glasses. It very often happens that the crystalline humour loses its transparency, and thus prevents the admission of the visual rays to the back parts of the eye. This disorder is called by the surgeons a *cataract.* As we know that the crystalline humour stands edgeways behind the pupil, all then that we have to do, is to make it lie flat in the bottom of the eye, and it will no longer bar out the rays that come in at the pupil. A surgeon, therefore, takes a fine straight awl, and thrusting it through the coats of the eye, he depresses the crystalline humour into the bottom of the eye, and there leaves it. Or sometimes he cuts the coats of the eye, the crystalline and the aqueous humour burst out together; in some hours the wound closes, a new aqueous humour returns, and the eye continues to see, by means of a glass, without its crystalline humour. This operation is called couching for the cataract. Cheselden once couched a boy who had been blind from his birth with a cataract. Being thus introduced, in a manner, to a new world, every object presented something to please, astonish, or terrify him. The most regular figures gave him the greatest pleasure, the darkest colours displeased, and even affrighted him. The first time he was restored, he thought he actually touched whatever he saw; but by degrees his experience corrected his numberless mistakes. More recently an interesting case of this kind has been described in the Philosophical Transactions by Mr. Ware.

The eye may be remedied when the crystalline humour only is faulty; but when there happens to be a defect in the optic nerve, then the disorder is almost always incurable. It is called the *gutta serena*, a disorder in which the eye is, to all appearance, as capable of seeing as in the sound state; but, notwithstanding, the person remains for life in utter darkness. The nerve is insensible, and scarcely any medical treatment can restore its lost sensations. This is the disorder so pathetically described by Milton in his lamentations on his own blindness.

In the course of the preceding lectures it was necessary to mention the angle of vision. But you will now be able better to understand why an object seen under a large angle, as near objects are, appears larger than the same object would at a distance. Thus men and women, when you meet them in the street, appear of their natural size, but if you look down upon them from the top of St. Paul's, they appear as small as puppets; and thus if you look from one end towards the other of a long and straight row of trees, you will see them gradually diminish, as they are further removed from your eye, though on a near inspection you would find them all of an equal size. The reason of this can be no longer a secret. You are already informed, that rays (or rather pencils of rays) are sent forth from every visible object, in all directions, some more and some less convergent. When you are near, therefore, you see the extreme points of any object by pencils of rays, which converge or meet in an angle more obtuse than when it is at a greater distance; and as the rays cross each other in the eye, a larger image is of course painted on the retina. Thus, in Pl. XV. fig. 67, the object ABC is seen by the eye at D, under the angle APC. and the image upon the retina *cba* is very large; but to the eye at E, placed at double the distance, the same object is seen under the angle A*p*C, which is only equal to half the angle APC. The image *cba*, therefore, is only half as large in the eye at E as in the eye at D; and this will sufficiently explain why objects *appear smaller in proportion to their distance from the eye.* Observe, however, that this proposition will admit of some exceptions, where the judgment corrects the sense. Thus, if a man six feet high (and not far distant from the spectator) is seen under the same angle with a dwarf two feet high (say at the distance of three feet from the spectator), still the dwarf will not appear as tall as the man, because the sense is corrected by the judgment, which makes a comparison of both with surrounding objects of known size. These exceptions will, however, in general, only take place with respect to near objects, and those with whose forms we are well acquainted.

From what has been said of the structure of the eye, you will also perceive the causes of distinct and indistinct vision. To see an object distinctly, it is necessary that every pencil of diverging rays, which reaches the eye from the object, should be converged to a point on the optic nerve, corresponding to that from which the rays have diverged. If, on the contrary they are brought in an unconverged state to the retina, you may easily conceive that the particles of light will be so scattered and dispersed, as to make an indistinct impression. This last defect takes place when the eye, by age or infirmity, is made flat, and consequently is not sufficiently convex to cause the rays to converge in their proper place; persons with this defect can often see objects better at a great distance than very near. The opposite fault to this is when the eye is too convex, when the rays will be made to unite too soon, before they reach the retina; persons with this defect, therefore, are called *short sighted* because they can only discern objects which are very near to the eye.

I have seen a very pretty contrivance in the shop of an optician, illustrative of the causes of weak and short sight. Two eyes were made of glass, as fig. 68 and 69, and the pencils of diverging rays, issuing from three points, were represented by threads of silk of three different colours. Thus in fig. 68, which represents weak or indistinct vision, you see the rays are not united in points when they reach the back of the eye, where the retina is situated; but if they were suffered to pass on without interruption, would converge in some part behind it. On the contrary, in figure 69, you see that, from the great convexity of the cornea, the rays are made to converge too soon, and, in effect, the perfect and distinct image is formed in the midst of the vitreous humour, and before it reaches the retina.

From what you have already learnt of the nature of lenses, you will be able to comprehend that the remedy for the former of these defects, that is, where the eye is too flat to cause the rays to converge in their proper place, is a double convex lens, the property of which is to increase the convergency of rays. The focus of this glass, however, must be exactly adapted to the wants of the eye for which it is intended. As therefore the eye grows flatter from age and infirmities, this will explain what is meant by "spectacles for all ages." Where the defect of sight is not great, as in younger persons, spectacles not very convex will suffice; but where the eye is very flat, as in old persons, glasses of a stronger magnifying power will be required.

On the contrary, *near* sighted eyes (such as fig. 69) being too convex, it is necessary to prevent the rays from converging too soon, which can only be done by means of a concave glass, which renders convergent rays less convergent. This glass, however, must also be exactly adapted to the necessity of the eye, otherwise the rays will not converge at the proper point.

I cannot quit this subject without noticing the gross stupidity of the atheist. Can any persons in their senses conceive that so nice, so exquisite an organ as the eye should be formed by *chance!* That by *chance* the humours should be disposed with the most perfect mathematical precision, so that a mistake to the breadth of a hair would be sufficient to defeat the purpose of vision! Yet these are the men, my young friends, who without understanding any principle of any one science, have the impudence to call themselves philosophers*! though in what their philosophy can consist, would require more than Newton possessed to be able to discover.

There is reason to believe, that the use of convex glasses, both as burning glasses and magnifiers, was not unknown to the antients; and, in the twelfth century, Alhazen, an Arabic philosopher, treated at some length of the magnifying power of these glasses. He was followed by our

* Why they have chosen to adopt this name no man can possibly devise. They might as well have called themselves architects, heralds, antiquarians, or by any other denomination with which they have no connexion whatever. Ask any of these pretended philosophers why a convex lens causes the rays of light to converge, or any similar question, and you will soon see whether they have any pretension to the name of philosophers.

truly illustrious countryman Roger Bacon, who demonstrated by experiment that a small segment of a glass globe would assist the sight of old persons. Thus he may be regarded as the person who first discovered the theory of spectacles, though they were not brought into use until the following century.

The telescope was invented about the end of the sixteenth century, and the discovery is commonly supposed to have been casual. The account which is generally received is, that the children of Zacharias Jansen, a spectacle-maker of Magdeburgh, trying the effect of a convex and concave glass united, found that when placed at a certain distance from each other, they had the property of making distant objects appear nearer to the eye; but the reason of this effect was not discovered till the time of Kepler.

The microscope was also an invention of Jansen or his children: and as it is rather a simpler instrument than the telescope, it will serve to introduce you very properly to a knowledge of these kinds of glasses. You already know that the nearer any body is to the eye, the larger is the angle under which it will be seen; but if placed too near, the image will be confused, because the divergence of the rays is then too great to admit of their being properly converged on the retina by the humours of the eye. In fact, an eye which is not near sighted cannot discern any object clearly at a shorter distance than six inches; and many objects are too small to be seen at that distance. This deficiency is supplied by the microscope.

The single microscope is only a small convex glass *cd*, (fig. 70,) having the object *ab* placed in its focus, and the eye at the same distance on the other side; so that the rays of each pencil, flowing from every point of the object on the side next the glass, may go on parallel in the space between the eye and the glass; and then, by entering the eye at C, they will be converged to as many different points on the retina, and form a large inverted picture AB upon it, as in the figure.

If, as in fig. 71, which represents the effect of this microscope, the object AB is in the focus of the lens DE, and the eye is in the other focus F, as much of the object will be visible as is equal to the diameter of the lens; for the rays AD and BE proceed through the extremities of the lens, and are united at F. Hence a maxim in optics—that *when an object is placed in one focus of a lens, and the eye in the other, any lineal dimension of the object appears just twice as large as it would to the naked eye*, whatever the size of the lens. For the lines FD and FE, if protracted as far as A and B, would form an image exactly twice as large. If the eye is nearer to the lens than the focus, it will see the object still larger; and if it is further off than the focus, it will not see it so large.

To find how much this glass magnifies, divide the least distance (which is about six inches) at which an object can be seen distinctly with the bare eye, by the focal distance of the glass; and the quotient will show how much the glass magnifies the diameter of the object. The most powerful single microscopes are very small globules of glass, which any person may make for himself by melting the ends of fine glass threads in the flame of a candle.

The double or compound microscope consists of an object-glass *cd*, (fig. 72,) and an eye-glass *ef*. The small object *ab* is placed at a little greater distance from the glass *cd* than its principal focus, so that the pencils of rays flowing from the different points of the object, and passing through the glass, may be made to converge and unite in as many points between *g* and *h*, where the image of the object will be formed: which image is viewed by the eye through the eye-glass *ef*. For the eye-glass being so placed that the image *gh* may be in its focus, and the eye much about the same distance on the other side, the rays of each pencil will be parallel, after going out of the eye-glass, as at *e* and *f*, till they come to the eye at *k*, where they will begin to converge by the refractive power of the humours; and after having crossed each other in the pupil, and passed through the crystalline and vitreous humours, they will be collected into points on the retina, and there form the large inverted image AB.

The magnifying power of this microscope is as follows. Suppose the image *gh* to be six times the distance of the object *ab* from the object-glass *cd*; then will the image be six times the length of the object: but since the image could not be seen distinctly by the bare eye at a less distance than six inches, if it is viewed by an eye-glass *ef*, of one inch focus, it will be brought six times nearer the eye; and consequently viewed under an angle six times as large as before; so that it will be again magnified six times; that is, six times by the object-glass, and six times by the eye-glass, which multiplied into one another make thirty-six times; and so much is the object magnified in diameter more than it appears to the bare eye; and consequently thirty-six times thirty-six, or one thousand two hundred and ninety-six times in surface.

The solar microscope is constructed upon similar principles. Two convex glasses are inclosed at their proper distances in a brass tube. This tube being fixed in the window-shutter of a dark room, the object is put between the two glasses, when a very large inverted image of it will be exhibited on the opposite wall, provided the sun shines sufficiently bright and clear upon the microscope. This instrument bears a strong analogy, therefore, to the camera obscura already described. Sometimes, three lenses are employed, and the magnifying power of the microscope proportionally increased.

What microscopes effect upon minute bodies very near, telescopes effect with regard to great bodies very remote; namely, they enlarge the angle in the eye under which the bodies are seen; and thus, by making them very large, they make them appear very near: the only difference is, that in the microscope the focus of the glasses is adapted to the inspection of bodies very near; in the telescope, to such as are very remote. Suppose a distant object at A B (see fig. 73), its rays come nearly parallel, and fall upon the convex glass *cd;* through this they will converge in points, and form the object E at their focus. But it is usually so contrived, that this focus is also the focus of the other convex glass of the tube. The rays of each pencil, therefore, will now diverge before they strike this glass, and will go through it parallel; but the pencils all together will cross in its focus on the other side, as at *e*, and the pupil of the eye being in this focus, the image will be viewed through the glass, under the angle *geh*, so that the object will seem at E under the angle D*e*C. This telescope inverts the image, and therefore is only proper for viewing such bodies as it is immaterial in what position they appear, as the sun, the fixed stars, &c. By adding two convex glasses, the image may be seen upright. The magnifying power of this, which is called the dioptric telescope, is found by dividing the focal distance of the object-glass by the focal distance of the eye-glass, and the quotient expresses the magnifying power.

The greatest inconvenience attending dioptric or refracting telescopes was found to be that which arises from what is called the *aberration* of light, which, when high magnifiers were used, that is, lenses much thicker in the middle than at the sides, produced often a confused, and sometimes a coloured image. This effect is the result of refraction, and it consists in different rays, according to their obliquity, uniting in different foci, though proceeding through the same lens. This will be easily understood by fig. 74. Suppose, then, PP to be a convex lens, and E *e* an object, the point E of which corresponds with the axis of the lens, and sends forth the rays EM, EN, EA, EM, EN, all of which reach the surface of the glass, but in different parts. The ray EA, which penetrates the centre of the glass, suffers no refraction; the rays EM, EM, which pass near EA, will be converged to a focus at F— But the rays EN, EN, which strike more obliquely near the edges of the glass, will be differently refracted, and will meet about G, nearer to the lens, where they will form another image G*g*. In this manner several images will be formed in different foci; and though to the eye which looks through the lens one image only will be apparent, yet that image, from being composed of so many combined, will be confused and distorted.

What is thus established in theory may be demonstrated by experiment, and that experiment is easy to make. Cover one side of a glass globe or of a thick lens with a piece of brown paper, making a row of pin-holes across the diameter of the lens very accurately at equal distances. Let the light which passes through the lens fall upon a sheet of white paper, and you will find that when the paper is held near the lens the spots of light will be nearly at equal distances; but if the paper is further removed, the intervals between the exterior spots become less than the intervals between the interior, and soon unite.

But there is a still further aberration, which is productive of even a greater inconvenience than this which I have now specified. When I come to treat of the prism and the prismatic colours, you will find that each particle of light is susceptible of a different degree of refrangibility, and consequently that every lens (especially high magnifiers) acts in some degree as a prism in separating the different coloured rays—Hence, if we suppose PP (fig. 75) to be a double convex lens, and *oo* an object at some distance from it, if the object *oo* were red, the rays proceeding from it would form a red image R*r*; if it were violet, an image of that colour would be formed at V*v* nearer the lens; and if the object were white, or any other combination of different coloured rays, these rays would have their respective foci at different distances from the lens, and form in fact a succession of images, in the order of the prismatic colours from R*r* to V*v*. As in the former case, these different images will form but one to the eye of the spectator; but it will be imperfect and coloured at the edges, as well as the field of view. Various remedies were devised for this defect. At length Mr. Dollond, finding that flint and crown glass had different refracting powers, and that crown glass (the common window glass) dispersed the rays of light less than any other, adapted two convex glasses of crown glass to a double concave of flint glass (which has the greatest dispersive power), so as exactly to fit, and by that means made them counteract each other, so that the field of view is presented perfectly colourless. These telescopes, therefore, are called *achromatic* (or colourless) telescopes.

The reflecting telescope accomplishes by reflecting the rays issuing from any object, what the last did by refracting them. Let *ab*, (Pl. XVI. fig. 76) be a distant object to be viewed: parallel rays issuing from it, as *ac* and *bd*, will be reflected by the metallic concave mirror, *cd* to *st*, and there brought to a focus, with the image a little further and inverted, agreeably to the effect of a concave mirror on light, as formerly described. The hole in the mirror *cd* does not distort or hurt the image *st*, it only loses a little light; nor do the rays stop at the image *st*; they go on, and cross a little before they reach the small concave mirror *en*: from this mirror the rays are reflected nearly parallel through the hole O, in the large mirror, to R; there they are met by the plano-convex lens *hi*, which brings them to a convergence at S, and paints the image in the small tube of the telescope close to the eye. Having by this lens, and the two mirrors, brought the image of the object so near, it only remains to magnify this image by the eye-glass *kr*; by which it will appear as large as *zy*.

To produce this effect, it is necessary that the large mirror should be ground so as to have its focus a little short of the small mirror, as at *q*; and that the small mirror should be of such concavity as to send the rays a little converging through the hole *o*; that the lens *hi* should be of such convexity as to bring those converging rays to an image at S; and that the eye-glass *kr* should be of such a focal length, and so placed in the tube, that its focus may just enter the eye through the small hole in the end of the tube.

To adapt the instrument to near or remote objects, or rather to rays, that issue from objects converging, diverging, or parallel, a screw, at the end of a long wire, turns on the outside of the tube, to take the small mirror nearer to, or further from, the large mirror; and so as to adjust their foci according to the nearness or remoteness of the objects. The sun-glass at the end of the small tube should be unscrewed, when any other object, except the sun, is looked at. This peculiar construction of the reflecting telescope is called the Gregorian telescope, from the name of its inventor.

To estimate the magnifying power of the Gregorian telescope, multiply the focal distance of the large mirror by the distance of the small mirror from the image S; then multiply the focal distance of the small mirror by the focal distance of the eye-glass *kr*; lastly divide these two products by one another, and the quotient is the magnifying power.

Sir Isaac Newton formed his telescope upon a somewhat different principle from that of Gregory. In his instrument, still known by the name of the Newtonian telescope, instead of the small concave mirror *en*, there is placed diagonally a plane mirror, on which the spectator looks through the side of the telescope by means of an eye-glass adapted to that purpose. The celebrated Dr. Herschel commonly uses the Newtonian telescope on an improved principle, and through that makes most of his observations.

Dr. Herschel's great telescope is however of a different construction. It has only one large concave reflector at the bottom of the tube; and the spectator stands with his back to the object, and looks in upon the reflector through an eye-glass. The magnifying power of this is the same as that of a Newtonian telescope would be of the same sized reflector; but, there being only one reflector, the quantity of light is less diminished. A minute description of this curious telescope is given under the word TELESCOPE in that universal dictionary called the *Pantologia*.

LECTURE XIV.

EXPERIMENTAL PHILOSOPHY.

COLOURS.

I HAVE explained the nature of vision, and that it is by means of the rays of light which are sent from the different objects that surround us to our eyes that they are rendered visible. But you are yet at a loss to understand whence proceed the infinite variety of colours in which the whole creation is superbly arrayed. You must be rendered sensible of these colours by means of the light: but you will be surprised to learn that the colours are not in the things, but in the light itself; and that every beam or pencil of light is composed of particles of different colours. "The blushing beauties of the rose, the modest blue of the violet," says Goldsmith, "are not in the flowers themselves, but in the light that adorns them: odour, softness, and beauty of figure, are their own; but it is light alone that dresses them up in those robes which shame the monarch's glory."

You must have observed yourselves, that the colours of objects are essentially altered by the light in which they are seen. The colours of various pieces of silk or woollen stuff are not the same by day as by candle light; but there is a common experiment which will yet more forcibly illustrate what I have been observing, and prove that colour is not in the objects, but in the light by which they are seen. Let a pint of common spirit, the cheapest will answer as well as the best, be poured into a soup-dish, and then set on fire: as it begins to blaze, let the spectators stand round the table, and let one of them throw a handful of salt into the burning spirit (still keeping it stirred with a spoon). Let several handfuls of salt be thus successively thrown in; the spectators will see each other frightfully changed, their colours being altered into a ghastly blackness. It is plain, then, that the solar rays are composed of matter different from the light which is emitted by this flame; and the truth is, that the light of a candle is somewhat different from both.

But the genius of Newton has enabled us to go still further in ascertaining the nature of light. He has analysed it with as much expertness as a chemist analyses any physical substance, and has divided it into its component parts. To this noble discovery the great philosopher was led rather by accident than by design; but a mind such as Newton's was able to improve whatever hint chance submitted to his view. It was in attempting to rectify the errors arising from the aberration of light in the glasses of the telescope, that his attention was directed to the wonderful effect which is produced by a prism.

The prism of the opticians is a triangular prismatic piece of glass, usually of the length of about three inches. If a small hole F, fig. 77, is made in the window-shutter, EG, of a dark chamber, and a beam of light, SF, proceeding directly from the sun (for the experiment will only succeed when the sun shines), is made to pass through the prism, ABC, an image of the sun, PT, will be represented on the sheet of paper, MN, fixed to the opposite wall. But you will observe two very extraordinary circumstances attending this representation of the sun. The first, that the figure is not round but oblong; and, secondly, if you will observe the figure in the plate, you will see that it is intended to represent different colours, and in the real image these colours will be found extremely vivid. On measuring the image, which philosophers have agreed in calling a *spectrum*, Sir Isaac Newton found that, at the distance of eighteen feet and a half from the prism, the breadth of the image was two inches and a half, and its length ten inches and one quarter, that is, nearly five times its breadth. The sides were right lines distinctly bounded, and the sides were semicircular, as in the plate. From this it was evident that it was still the image of the sun, but elongated by some refractive power in the glass. In the image PT the colours succeeded in this order from the bottom at T, to the top at P, namely red, orange, yellow, green, blue, indigo, violet*.

Unable as yet to account for the phænomenon, he was induced to try the effect of two prisms, and he found that the light, which by the first prism was diffused into an oblong, was by the second reduced to a circular form, as regularly as if it had passed through neither of them. After various conjectures and experiments, he had recourse, at length, to what he calls the *experimentum crucis.* At the distance of about twelve feet from the prism, which was close to the aperture F, he placed a board which might receive the image in the same manner as the sheet of paper MN. In this board there was also a small hole, through which some of the light might pass; behind this hole, then, he placed a second prism, and, by moving the first prism, he made the several parts of the image cast by it on the board to pass successively through the hole, so as to be refracted again upon the wall by the second prism. He found then, that the different colours of the spectrum, when permitted to pass through the hole in the board, were incapable of further decomposition:

* These, taken in an inverse order, are readily called to mind, by means of the word *vibgyor,* formed of the successive initials of *v*iolet, *i*ndigo, *b*lue green, *y*ellow, *o*range, *r*ed.

that the red rays continued red, the orange the same, &c. The cause of the phænomenon, therefore, was no longer a secret. It was plain that every beam of light consisted of particles different in colour, or which rather have the effect of producing different colours, and that all of them blended together formed white. It was further evident, that the particles of one colour were more refrangible than those of another; and therefore those which formed the upper part of the image or spectrum suffered a much greater refraction than those at the bottom; in other words, were more under the influence of the attractive powers of the glass. Hence it was further evident why the figure or spectrum was of an oblong form instead of round; for the particles of light, being differently refrangible, were spread out longitudinally by the action of the prism.

Various experiments will convince you that white light is no more than a compound of these parti-coloured rays or particles. Thus, if, instead of the sheet of paper MN, you substitute the large convex glass D, see fig. 78, in its place, the scattered rays will be converged and united at W, where, if the paper is placed to receive them, you will see a circular spot of a lively white. At W also the rays will cross each other; and if the paper is removed a little further, you will see the prismatic colours again displayed as at RV, only in an inverted order, owing to the crossing of the rays.

To show further in what manner *white* is produced. Let two circles be drawn, as in fig. 79, on a smooth round board ABCDEFG, and the outermost of them divided into three hundred and sixty equal parts or degrees: then draw seven right lines, as A, B, &c. from the centre to the outermost circle; making the lines A and B include eighty degrees of that circle; the lines B and C forty degrees; C and D sixty; D and E sixty; E and F forty-eight; F and G twenty-seven; G and A forty-five. Then, between these two circles, paint the space AG red, inclining to orange near G; GF orange, inclining to yellow near F; FE yellow, inclining to green near E; ED green, inclining to blue near D; DC blue, inclining to indigo near C; CB indigo, inclining to violet near B; and BA violet, inclining to a soft red near A. This done, paint all that part of the board black which lies within the inner circle; and putting an axis through the centre of the board, let it be turned very swiftly round that axis, so that the rays proceeding from the above colours may be all blended and mixed together in coming to the eye; and then the whole coloured part will appear like a white ring, a little grayish; not perfectly white, because no colours prepared by art are perfect.

Any of these colours, except red and violet, may be made by mixing together the two contiguous prismatic colours. Thus, yellow is made by mixing together a due proportion of orange and green; and green may be made by a mixture of yellow and blue.

The theory of colours is therefore now unfolded. Those bodies, or those parts of bodies, which have the property of reflecting only the red-making rays, will appear red; those which reflect the violet will be violet, &c.; and those which reflect some rays of one colour and some of another will be the intermediate shade or colour between both; and as white is a compound of all the seven primary colours, so black is an entire deprivation of them all; and when an object appears black, the light is completely absorbed, or at least not reflected by it. To prove, however, still more forcibly that colour is not in the objects, but in the light itself; no object whatever can reflect any other kind of light than that which is thrown upon it; and when any one of the primitive rays has been separated from the rest, nothing can change its colour. Send it through another prism, expose it in the focus of a burning glass, yet still its colour continues unaltered; the red ray will preserve its crimson, and the violet its purple beauty; whatever object falls under any of them soon gives up its own colour, though ever so vivid, to assume that of the prismatic ray. Place a thread of scarlet silk under the violet-making ray, the ray continues unaltered, and the silk instantly becomes purple. Place an object that is blue under a yellow ray, the object immediately assumes the radial colour.

In short, no art can alter the colour of a separated ray; it gives its tint to every object, but will assume none from any; neither reflection, refraction, nor any other means can make it forego its natural hue; like gold, it may be tried by every experiment, but it will still come forth the same.

In whatever manner we consider the colour of a single prismatic ray, we shall have new cause to admire the beauties of nature. Whatever compositions of colouring we form, if examined with a microscope, they will appear a rude heap of different colours unequally mixed. If by joining, for instance, a blue with a yellow, we make the common green, it will appear to the naked eye moderately beautiful; but when we regard it with a microscopic attention, it seems a confused mass of yellow and blue parts, each particle reflecting but one separate colour: but very different is the colour of a prismatic ray; no art can make one of equal brightness, and the more closely we examine it the more simple it appears. To magnify the parts of this colour would be but to increase its beauty.

The red and orange rays, you have seen, are least subject to refraction, or are least turned out of their way by the interposition of the glass; they are therefore, we may conclude, either larger than the rest, or propelled with greater force; in technical language, they have the greatest momentum. Agreeably to this we find, that when the eyes are very weak they can scarcely support a scarlet colour; its impressions are too powerful, and, next to the solar beam itself, dazzle and disturb the organ. On the contrary, the more refrangible the rays (the violet for instance), the less forcibly they strike the eye; and green, the intermediate colour, is the most agreeable, and is that in which Providence has chosen to array the meadows and the woods, in a delightful variety, the diversities of green being greater than those of any other colour.

Of all the objects of nature the rainbow exhibits the prismatic colours in the greatest perfection. It is, indeed, a natural prism, and separates the component particles of light with the same accuracy and precision.

The rainbow was one of those phænomena which astonished and perplexed the antients; and, after many absurd and unsuccessful conjectures, their best philosophers, Pliny and Plutarch, relinquished the inquiry as one which was above the reach of human investigation. In the year 1611 Antonio de Dominis made a considerable advance, however, to the true theory, by suspending a glass globe in the sun's light, when he found that, while he stood with his back to the sun, the colours of the rainbow were reflected to his eye in succession by the globe, as it was moved higher or lower. He was, however, unable to account for the production of the different colours, as the experiments with the prism had not yet been made, and it was reserved for Newton to perfect the discovery.

To begin, however, with the experiment of the former philosopher, let us suppose ourselves in his place. Let A, (Pl. XVII. fig. 80,) be a glass globe, and S*d* a ray from the sun, and falling on the globe at *d*; it will, in that place, suffer a refraction, and instead of going on to *c* will be bent to *n*. From *n* a part of the light will be reflected (for a part will necessarily pass through), and falling obliquely at *o*, it will again be refracted. In this case you see that the globe, from its form, will act in some measure like a prism, and the ray will be separated into its component parts. An eye, therefore, situated at *g*, will see the red rays at the line just above the orange, &c. and so on to the violet. Now you will recollect, that in a shower of rain there are drops at all heights, and therefore the eye situated at *g* will see all the different colours.

This will account for the first or primary bow, which you see is thus formed by two refractions and one reflection; but there is often a second bow on the outside of the other, which is rather fainter, and which is made by two refractions and two reflections. To explain this, take a similar glass globe, B, fig. 81. Let the ray T in that enter at the bottom of the globe at *r*, where it is refracted, and part of the light will escape at *s*, and the rest, instead of escaping to *w*, will be reflected to *t*; from this, part will escape to *x*, and part will be again reflected to *u*, where it suffers another refraction, and is sent to the eye at *g*, where the violet rays will be first visible, and then the others in succession.

Now each drop of rain may be considered as a small globe, and within a certain range will refract and reflect the light in the manner above described. To make the matter still plainer, therefore, let us for the present imagine only three drops of rain, and three degrees of colours in the section of a bow (fig. 82). It is evident that the angle CFE is less than the angle BFE, and that the angle AFE is the greatest of the three. This largest angle then is formed by the red rays, the middle one consists of the green, and the smallest is the purple. All the drops of rain, therefore, that happen to be in a certain position to the eye of the spectator, will reflect the red rays, and form a band or semicircle of red; those again in a certain position will present a band of green, &c. If he alters his station, the spectator will still see a bow, though not the same bow as before; and if there are many spectators, they will each see a different bow, though it appears to be the same.

The phænomenon assumes a circular appearance, because it is only at certain angles that the coloured or refracted rays are visible to our eyes, as is evident from the experiment with the glass globe, which will only refract the rays in a certain position. The least refrangible, or red rays, make an angle of forty-two degrees two minutes, and the most refrangible, or violet rays, an angle of forty degrees seventeen minutes. Now if a line is drawn horizontally from the spectator's eye, it is evident that angles formed with this line, of a certain dimension in every direction, will produce a circle, as will be evident by only attaching a cord of a given length to a certain point, round which it may turn as round its axis, and in every point will describe an angle with the horizontal line of a certain and determinate extent.

From an analytical investigation (which, however, it would not be consistent with our plan to introduce here*) it results that the total breadth of the *interior* bow is 2° 15′, that of the exterior bow 3° 40′, and the distance between them 8° 25′.

We see a greater or a less part of the rainbow, according as the sun is more or less elevated above the horizon. When the luminary is near the plane of the horizon, then the axis of vision (as EF) which is at the same time, that of the cone formed by all the effectual rays, coincides with the horizon; and the rainbow, in this case, is a semicircle. In proportion as the sun is elevated, the axis EF sinks below its first position, and the

* It may be seen in a note at page 218, vol. ii. of Gregory's translation of Haüy's Philosophy.

bow regularly diminishes. Lastly, when the sun is 42° above the horizon, the axis being sunk the same number of degrees below that circle, the summit of the rainbow touches the horizon: so that, when the sun is higher than this no primary bow can be seen. A portion, however, of the exterior or secondary bow, may be seen, if the sun have any elevation between 42° and 54°.

If we stand on an eminence, when the sun is at the horizon, a rainbow exceeding a semicircle, (and, indeed, in favourable circumstances, approaching to an entire circle), may be seen.

As the cause of colours must be now apparent to you, and as it is evident that they must proceed from some quality in bodies or their surfaces, which causes them to reflect rays of a particular hue, you will easily understand why some bodies, which are called semipellucid, afford one colour by transmitted, and another by reflected light. The truth is, the beam of light in passing through them is dissected and separated, and part of one colour is permitted to pass through, and part is sent back. If a solution of a wood called lignum nephriticum is put into a clear phial, when viewed only by the reflected light which falls upon it, the solution will appear blue; but if held up against the light, and seen through, the colour will be a fine yellow. The same is found to be the case with some precious stones, and some glass compositions. Thus, if a small quantity of arsenic is mixed in the composition of glass, the mass will appear bluish white by the reflected light, but orange by that which is transmitted through it.

The blue colour of the sky may be accounted for upon this principle. The atmosphere may be considered as a semipellucid medium, which is loaded with small and light particles of vapour; and these particles may be compared with the particles of arsenic, which are mingled in the glass above mentioned. If the air is very heavily charged with these vapours, therefore, a large proportion of the light will be reflected, and that dusky whiteness appears which distinguishes mists and fogs; but in a clear state of the atmosphere only the weaker and more refrangible rays, such as the blue, violet, &c. are reflected, and hence proceeds the blue colour of the sky.

On the same principle depends the green colour of the sea. It is a mixed mass, charged with heterogeneous particles. All the more refrangible rays, therefore, are reflected, while the stronger rays, the red, orange, &c. are transmitted. Thus Dr. Halley, in a diving-bell, sunk many fathoms deep in the sea, observed, that when he extended his hand out of the bell into the water, the upper part of it was red, and the lower part a blueish green. The redness was occasioned by the strong red rays, which in their progress through the mass of water were intercepted and reflected by his hand; while, on the contrary, the heterogenous particles dispersed through the water reflected only the refrangible rays, so as to afford the appearance of green. These principles applied to many other of the phænomena of nature will serve to explain their causes; and if they excite you but to use your own understandings, and to think for yourselves, this sketch of the phænomena of light and colours may be of as essential service to you as the most laboured detail.

Since the former editions of this work were published, philosophers have entered into a new field of investigation in the region of optics. Besides the properties of light indicated by the words *reflection*, *refraction*, and *inflection*, there has recently been discovered another, denominated *polarization*. Dr. Sebeck in Germany, Dr. Brewster in Scotland, and M. M. Malus and Biot in France, are the philosophers to whom we owe the principal discoveries in this new track of inquiry.

When the particles of light traverse crystallized bodies, endowed with a double refraction (such, for example, as Iceland spar), they experience about their centre of gravity divers motions, which depend upon the nature of the forces which the particles of the crystal exercise upon them. Sometimes the effect of these forces is limited to disposing all the moleculæ of the same ray similarly the one to the other, in such manner that their homologous faces are turned towards the same parts of space. This is the phænomenon to which Malus gave the name of *polarization*, assimilating the effect of the forces to that of a magnet, which should turn the poles of a series of magnetized needles all in the same direction. When this disposition obtains, the luminous particles are retained in the whole extent of the crystal, and experience no farther motion about their centre of gravity. But there exist other cases where the particles which traverse the crystal are not fixed to a constant position. During all the time of their passage, they oscillate about their centre of gravity with computable velocities and periods. Sometimes, again, they turn upon themselves, as it were, with a continued motion of rotation.

The various phenomena, thus briefly alluded to, are classified under the terms *fixed* and *moveable polarization*. The philosophers above named have established, illustrated, and confirmed them, by a great variety of striking experiments; and some new instruments (such, for example, as the *calorigrade*, now sold by opticians) have originated from these researches. The train of discoveries connected with polarization is by no means completed. It has, however, already furnished a most striking confirmation of the Newtonian theory of colours, and of the rainbow, establishing their correct accordance with nature and truth, even in the minutest particulars.

The best account which has yet been given to the world of the discoveries relating to *polarization*, may be found in the fourth Vol. of Biot's

Treatise on Natural Philosophy. This philosopher, however, has fallen into some strange errors in his explication: we, therefore, hope that Dr. Brewster, whose researches into the nature of polarization have been extensive, elaborate, and successful, will speedily favour the world with a connected view of the whole subject.

LECTURE XV.

EXPERIMENTAL PHILOSOPHY.

THE LAWS OF MOTION.

Every thing in mechanics depends upon very simple principles, and may be resolved ultimately into the power of gravity and the laws of motion.

In treating of gravitation, in our second lecture, it was shown to be that kind of attraction which subsists between the mass of the earth and all those bodies which are on its surface. It is that which, in the stated revolutions of this planet, prevents us, and all the bodies which surround us, from falling into infinite space; and which draws so forcibly every thing whatever towards the centre of the earth.

That this attraction is greater or less at different distances is generally allowed; a body which at one semidiameter of the earth weighs one pound will have four times less weight at two semidiameters, and nine times less at three. At small distances, however, we are not sensible of this difference in weight; for though we could be elevated a mile above the earth's surface, when we consider that its diameter is about eight thousand miles, we shall easily see that the small difference which this would produce is scarcely to be estimated.

Falling bodies, however, we know, acquire an accelerated or increased force, according to the height from which they are precipitated; but this must be accounted for from different principles. Every man is sensible that the fall of a stone is to be dreaded in proportion to the height from which it descends. If it falls from only a foot above his head, it is not likely to be so fatal as if it fell from the parapet of a high house. The falling body, therefore, must of necessity acquire an increase of velocity in its descent; and, in fact, it is said that a leaden bullet let fall from one of the steeples of Westminster Abbey acquired velocity sufficient to pierce through a deal board.

This effect must therefore be referred to the law of acceleration conjointly with the first law of motion, as laid down by Sir Isaac Newton, which is, that "all bodies are indifferent to motion and rest: in other words, a body at rest will continue in that state, unless put in motion by some external impulse; and a body in motion will continue that motion for ever, unless stopped by some external obstruction." This property of matter is termed, in the technical language of philosophy, its *vis inertiæ*.

To apply this to the case immediately in point, it is evident that the bullet which is dropped from the steeple of Westminster Abbey, having, by the power of gravity, once acquired a certain degree of motion, would continue to fall, by the motion it had received by the first impulse, even if the cause were to cease. For instance, if when it had fallen half way it were possible to deprive it of gravity, it would still, by the above law, continue its motion, and in the direction in which it was sent, as a stone continues to proceed, when thrown by the hand, without any new impulse. The power of gravity, however, does not cease, and therefore every inch the bullet falls it receives an increase of motion. Thus, if in the space of one second it falls one pole (sixteen feet and a half), it will then have acquired as much swiftness or velocity as will carry it through three poles in the next second, through five in the third, through seven in the fourth, and nine in the fifth. This will account for its accelerated motion, and for the increased force with which it falls near the bottom. Thus the time which bodies take in falling is easily calculated; for, if they fall about one pole in the first second, which is what they nearly do by the force of gravity, they will then fall three in the next, and in five seconds they will fall about twenty-five poles, or three hundred feet. These spaces, however, are a little diminished by the resistance of the air.

As heavy bodies are uniformly accelerated in their descent, they are as uniformly retarded by the power of gravity in their ascent. Thus, if I were to throw the bullet up to the steeple of Westminster Abbey, I must give it just as much force as it acquired in its descent. Thus again, the body D in rolling down the inclined plane, A B (Plate XVIII. fig. 83) will acquire sufficient velocity by the time it arrives at B to carry it up nearly to C ; and if the plane were perfectly smooth, and the air gave no resistance, it would carry it up quite to that point: it is upon this principle the *pendulum* is constructed. You all know, I conceive, that a simple pendulum consists of a bob or ball fixed to a small string or wire. If therefore the bob (fig. 84) is let go at *a*, it will fall to *d*, and by the velocity it acquires in the fall it will rise to *c*: this is called an oscillation ; and if a pendulum were put in motion in a space quite void of air, and free from all resistance from friction on the point of suspension, it would move for ever. Pendulums vibrate in proportion to the square roots of their lengths, and the vibrations of the same pendulum are always performed in the same space of time. Hence their great utility in measuring time ; for a pendulum of thirty-nine inches, one-fifth will vibrate an aliquot part of the time the earth is turning on its axis, that is, 1-86400dth part, or sixty times in a minute. Near the equator, however, pendulums move slower than near the poles ; and they are also subject to variations and irregularities from heat and cold, which causes the metals, of which the rods are usually formed, to lengthen or contract.

It is from that sluggishness of motion, which is called the *vis inertiæ* of bodies, that there proceeds something like an *endeavour* in all bodies to preserve the state in which they are; when at rest to continue in a state of rest, and when in motion to continue in motion. This position may seem abstruse, but it will admit of illustration by the most common facts. If I push a bowl of water with my hand, the water flies backwards over the edge upon my hand, for it endeavours to continue in the state of rest in which it was. But if I take the bowl in my hand, and run along with it, and suddenly stop short, the water flies forward the way I was running, from its *vis inertiæ*, or tendency to continue in the same state of motion. In the same manner, if I am sitting in the front of a carriage, which, after going very fast, stops suddenly, I am jolted from my seat, and my head will, without care, drive through the front glass of the carriage.

It is a plain and obvious principle, that the greater the quantity of matter is which any body contains, the greater will be its *vis inertiæ*. The heavier any body is, the greater is the power which is required, either to set it in motion or to stop it. So again, the swifter any body moves, the greater is its force; as was sufficiently exemplified in the case of a bullet, which was supposed to fall from the steeple of Westminster Abbey. But to make the matter still plainer: if the roller *a* (fig. 85) leans against the obstacle *b*, it will be found incapable of overturning it, but if *a* is taken up to *c*, and suffered to roll down the inclined plane against *b*, it will overturn it instantly. It is plain, therefore, that by its continued motion the roller *a* has acquired a force which it had not in itself. The stroke which *a* strikes at *b* is called its momentum. Hence results the well-known maxim in philosophy, which I have before had occasion to repeat to you—"That the whole momentum, or quantity of force, of any moving body, is estimated by the quantity of matter multiplied by the velocity or swiftness with which it moves." When the products, therefore, arising from multiplying the quantity of matter in any two bodies by their respective velocities, are equal, we say their momenta, or moving forces, are the same. Thus, if a body, which I call A, weighs forty pounds, and moves at the rate of two miles in a minute; and another body, which I call B, weighs only four pounds, and moves at the rate of twenty miles in a minute, the entire force with which these two bodies will strike each other would be equal, and each of them would require an equal force to stop it. For forty multiplied by two gives eighty, the force of A; and twenty multiplied by four is eighty, the force of B.

Upon this easy principle depends much of practical mechanics: and it holds universally true, that when two bodies are suspended on any machine, so as to act contrary to each other; if the machine is put into motion, and the perpendicular ascent of one body multiplied into its weight is equal to the perpendicular descent of the other body multiplied into its weight, those bodies, how unequal soever in their weights, will balance one another in all situations: for, as the whole ascent of one is performed in the same time with the whole descent of the other, their respective velocities must be directly as the spaces they move through; and the excess of weight in one body is compensated by the excess of velocity in the other. Upon this principle it is easy to compute the power of any mechanical engine, whether simple or compound; for it is but only finding how much swifter the power moves than the weight does (i. e. how much further in the same time), and just so much is the power increased by the help of the engine.

The second law of motion laid down by Sir Isaac Newton is—"That the alteration of the state of any body from rest to motion, or from one motion to another, is always in proportion to the force which is impressed, and in the direction of that force."

All motion is naturally rectilinear. A bullet projected by the hand, or shot from a cannon, would for ever continue to move in the same direction it received at first, if no other power diverted its course. When therefore we see a body move in a curve of any kind whatever, we conclude it must be acted upon by two powers at least; one putting it in motion, and another drawing it away from the rectilinear course in which it would otherwise have continued to move: and whenever that power, which bent the motion of the body from a straight line into a curve, ceases to act, the body will again move on in a straight line touching that point of the curve in which it was when the action of that power ceased. For example, a pebble moved round in a sling ever so long a time, will fly off the moment it is set at liberty, by slipping one end of the sling cord: and will go on in a line touching the circle it described before; which line would actually be a straight one, if the earth's attraction did not affect the pebble, and bring it down to the ground. This shows that the natural tendency of the pebble, when put into motion, is to continue moving in a straight line, although by the force that moves the sling it is made to revolve in a circle.

From this maxim it will evidently appear, that when two forces act at once upon the same body, in different directions, it will go in neither, but in a course between both. If the billiard ball *a* (fig. 86) is struck at once by the two cues *b* and *c*, it will be impelled forward in the diagonal or middle line, whereas *b* would have impelled it in the line *e*, and *c* in the line *d*.

Or if a boat (fig. 87) is drawn up the stream by two men on the opposite banks, it will follow the direction of neither exactly, but will proceed directly in the middle of the stream.

Suppose again (Pl. XIX. fig. 88) the body A to represent a ship at sea; and that it is driven by the wind, in the right line AB, with such a force as would carry it uniformly from A to B in a minute: then suppose a stream or current of water running in the direction AD, with such a force as would carry the ship through an equal space from A to D in a minute. By these two forces, acting together at right angles to each other, the ship will describe the line AEC in a minute; which line (because the forces are equal and perpendicular to each other) will be the diagonal of an exact square.

If the acting forces are equal, but at oblique angles to each other, so will the sides of the parallelogram be: and the diagonal run through by the moving body will be longer or shorter, according as the obliquity is greater or smaller. Thus, if two equal forces act conjointly upon the body A, (fig. 89) one having a tendency to move it through the space AB in the same time that the other has a tendency to move it through an equal space AD; it will describe the diagonal AGC in the same time that either of the single forces would have caused it to describe either of the sides. If one of the forces is greater than the other, then one side of the parallelogram will be so much longer than the other. For if one force singly would carry the body through the space A E, in the same time that the other would have carried it through the space A D, the joint action of both will carry it in the same time through the space A H F, which is the diagonal of the oblique parallelogram A D E F.

If both forces act upon the body in such a manner, as to move it uniformly, the diagonal described will be a straight line; but if one of the forces acts in such a manner as to make the body move faster and faster, then the line described will be a curve. And this is the case of all bodies which are projected in rectilinear directions, and at the same time acted upon by the power of gravity, which has a constant tendency to accelerate their motions in the direction wherein it acts.

This last is an observation of great importance, as it is the foundation of the beautiful system of Newton concerning the planetary motions. The force which impels these bodies forward in a rectilinear direction, is called the projectile or the centrifugal force, as driving them from the centre; and the force which draws it towards the centre, or the power of gravity, is called the centripetal force. Thus, if the body A (fig. 90) is projected along the straight line A F H in open space, where it meets with no resistance, and is not drawn aside by any power, it will go on for ever with the same velocity, and in the same direction. But if, at the same moment the projectile force is given it at A, the body S begins to attract it with a force duly adjusted *, and perpendicular to its motion at A, it will then be drawn from the straight line AFH, and forced to revolve about S in the circle ATW; in the same manner, and by the same law, that a pebble is moved round in a sling. And if, when the body is in any part of its orbit (as suppose at K), a smaller body, as L, within the sphere of attraction of the body K, is projected in the right line LM, with a force duly adjusted, and perpendicular to the line of attraction LK; then the small body L will revolve about the large body K in the orbit NO, and accompany it in its whole course round the yet larger body S. Here S may represent the sun, K the earth, and L the moon. But of this we shall treat more at large in the lectures on astronomy.

These principles will serve to explain many facts which will come from time to time under your observation. Thus if a leaden ball is dropt from the mast-head of a ship, under swift sail, you would suppose, before the ball would reach the deck, the ship would be slid from under it, and that it would fall behind the ship into the sea.

* To make the projectile force a just balance to the gravitating power, so as to keep the planet moving in a circle, it must give such a velocity as the planet would acquire by gravity, when it had fallen through half the semidiameter of that circle.

This is not the fact; for the ball falls down by the side of the mast, as if the ship were at anchor. Why? Because the ball is under the influence of two forces; one horizontal, by the motion of the ship, which is the same as if you had sent it forwards from your hand with the same degree of velocity as the ship moves at; the other force is perpendicular, by the power of gravity: so that though it appears to fall perpendicularly, it does not, but describes, in space, the same kind of semi-parabola as a ball shot from a gun.

If I throw a log of wood into the Thames, when the wind is across the river, the log will not obey the current, by going down the river, nor the wind, by going across the river, but will go in an oblique direction made up of the two.

The third law is, that " re-action is always equal to action." Thus, in consequence of this principle, the resistance of a body at rest, which is acted or pressed upon, acts against a moving body with a certain degree of power, and produces the same effects as an active force would have done in the same direction. Thus, if I strike an anvil with a hammer, the anvil exerts against the hammer the same force with which it is struck itself. Hence a common trick in the country, of a man lying on the ground with a large anvil on his breast, and suffering a strong man to strike it with a sledge hammer with all his might. If the anvil be very large, its *vis inertiæ* resists the force of the blow, and the man is perfectly safe. If the anvil were very small, only the weight of a pound or two, the first stroke would kill the man.

A pretty experiment of Mr. Walker's will serve also to illustrate this part of the subject. "Let *a* be a little cannon, (Pl. XX. fig. 91.) and *b* a hollow piece of iron or brass, to slip on pretty tight upon *c c*, and of the same weight as *a*. Now if half a thimbleful of gunpowder be put in *a*, and *b* shut upon it, both being suspended by two strings; if the powder is fired, the parts *a* and *b* will be thrown equally distant from *r*, the center where they hung; showing the re-action to be equal to the action. Hence a heavy gun seems to recoil less than a light one, on account of its greater *vis inertiæ;* otherwise its re-action is the same, with the same charge."

Hence it is evident, that when a load is drawn by a horse, the load acts against the motion of the horse, and the action of the animal is as much impeded by the load, as the motion of the load is promoted by his efforts. Many other illustrations of these laws may be seen in the larger treatises of mechanics.

Before I proceed to the consideration of the six mechanic powers, it is necessary to say a few words on what is called the *centre of gravity.*

The centre of gravity is that point of a body in which the whole force of its gravity or weight is united, and to which its action may usually be referred. Whatever, therefore, supports that point, bears, in fact, the weight of the whole body; and while it is supported the body cannot fall, because all its parts are in perfect equilibrium about that point. Thus, if I endeavour to balance my cane, by laying it across upon my finger, after some time I find a place where neither end will preponderate. The part, then, which rests upon my finger is the centre of gravity. An imaginary line drawn from the centre of gravity of any body towards the centre of the earth, is called the *line of direction*, and it is in this line all heavy bodies will descend.

The difficulty of sustaining a tall body upon a narrow foundation will be evident, if you attempt to balance your cane with its small end upon your finger. Its centre of gravity is somewhere about the middle of the cane, and unless you have sufficient dexterity to keep the foundation on your finger perpendicular under the centre of gravity, it will undoubtedly fall. In this consists the great difficulty of posture-masters and rope-dancers. The dancer on the rope balances himself by a long pole loaded at both ends with lead, and keeps his eye steadily on some point exactly in the line of the rope, by which he can see whether his centre of gravity is either on one side or the other of his slippery foundation, and if any irregularity takes place he rectifies it by his balancing pole.

Every body stands firm on its base, when the f direction falls within such base; for in this the body cannot be made to fall, without first raising the centre of gravity higher than it was before. Thus, the inclining body ABCD, (fig. 92.) whose centre of gravity is E, stands firmly on its base CDIK, because the line of direction EF falls within the base. But if a weight, as ABGH, is laid upon the top of the body, the centre of gravity of the whole body and weight together is raised up to L; and then, as the line of direction ID falls without the base at D, the centre of gravity I is not supported; and the whole body and weight tumble down together.

As a practical illustration of this, I shall mention that the tower of Pisa (fig. 93.) leans sixteen feet out of the perpendicular, and strangers are consequently afraid to pass under it. If, however, the materials will hold together, there is no necessity for any such apprehension. For if the plummet *c* is let fall from its centre of gravity, you will see that the line of direction is within its base or foundation, and therefore it has stood without a miracle these three hundred years.

The nearer the centre of gravity and the line of direction coincide, the firmer any body stands upon a horizontal plane. If the plane is inclined a body will slide down it, if the line of direction falls within the base; but it will tumble down when that line falls without the base. Thus the body A (fig. 94.) slides down the inclined plane C D, while the body B rolls down upon it.

The broader the base the firmer any body stands; thus you find you stand firmer with your feet a little asunder than when close together; and in the former case it will require a much greater force to push you down. Hence the advantage of walking with the feet rather wide asunder, on a slippery pavement in frosty weather. Whenever the line of direction, however, falls without the base of our feet, we necessarily fall; "and it is not only pleasing," says Mr. Ferguson, "but even surprising, to reflect upon the various and unthought-of methods and postures which we use to retain this position, or to recover it when it is lost. For this purpose we bend our body forward when we rise from a chair, or when we go up stairs: and for this purpose a man leans forward when he carries a burden on his back, and backwards when he carries it on his breast; and to the right or left side as he carries it on the opposite side." A thousand more instances might be added, but they will readily suggest themselves to the mind of reflecting persons.

LECTURE XVI.

EXPERIMENTAL PHILOSOPHY.

THE MECHANIC POWERS.

MAN, considered as to his bodily structure, is but a feeble creature; it is mind which gives him a superiority over other animals. Contrivances to assist his natural powers we have reason to believe took place at a very early period of society, as we find few nations, even in the most savage state, which are entirely without them. It is philosophy, however, which explains their theory and uses, and which extends their application.

When we survey the vast variety of complex machines, which one of our great manufactories, for instance, exhibits, we are struck with astonishment, and the creative genius of man appears to the greatest advantage; but the surprise of the unscientific person will be increased, when he learns that this vast assemblage of mechanism is reduced into six simple machines or powers, from which, and their different combinations, the most stupendous works of human art are produced. These machines are; 1. the lever; 2. the wheel and axle; 3. the pulley; 4. the inclined plane; 5. the wedge; and 6. the screw.

1. The lever is, perhaps, the simplest of all

the mechanic powers, and was probably the first which was brought into use. It is a bar of iron or wood, one part of which is supported by a prop, and upon that prop all the other parts turn as on their centre of motion. You see the lever made use of in one form or other every day when a labourer takes a hand-spike, or large stake, and placing a stone under some part near the end, by putting the extremity under a cask, a piece of timber, or any other body, and attempts to move it, by pulling at the other end, he makes use of a lever. The handle of a pump is a lever also; even the poker with which I raise the fire is a lever, the bar of the grate is the prop, and at the end which I hold in my hand is applied the strength or power. This is, however, not the only kind of lever, for in fact there are three different sorts or orders of these instruments. The first is that which I have been describing, viz. when the prop is placed between the weight to be raised and the power (see fig. 95.) In this figure ABC is the lever; D is the fulcrum or prop; and the part AB and BC, on different sides of the prop, are called the arms of the lever. It is demonstrable that in this instrument the nearer the prop is to the end A, and the longer the arm BC is, the less force will be required to effect any given purpose. This is, indeed, reduced to a matter of experiment. For let P represent a power, whose gravity is equal to one ounce; and W a weight, whose gravity is equal to twelve ounces. Then, if the power is twelve times as far from the prop as the weight is, they will exactly counterpoise; and a small addition to the power P will cause it to descend, and raise the weight W; and the velocity with which the power descends will be to the velocity with which the weight rises, as twelve to one: that is, directly as their distances from the prop; and consequently, as the spaces through which they move. Hence it is plain that a man who by his natural strength, without the help of any machine, could support a hundred weight, will by the help of this lever be enabled to support or rather raise twelve hundred. If the weight is less, or the power greater, the prop may be placed so much farther from the weight, and then it can be raised to a proportionably greater height. For, universally, if the intensity of the weight multiplied into its distance from the prop is equal to the intensity of the power multiplied into its distance from the prop, the power and weight will exactly balance each other; and a little addition to the power will raise the weight. Thus, in the present instance, the weight W is twelve ounces, and its distance from the prop is one inch; and twelve multiplied by one is twelve; the power P is equal to one ounce, and its distance from the prop is twelve inches, which multiplied by one is twelve again; and therefore there is an equilibrium between them. So, if a power equal to two ounces is applied at the distance of six inches from the prop, it will just balance the weight W; for six multiplied by two is twelve, as before. And a power equal to three ounces placed at four inches distance from the prop would be the same; for three times four is twelve; and so on, in proportion.

The *statera*, or Roman *steelyard*, is a lever of this kind, and is used for finding the weights of different bodies by one single weight placed at different distances from the prop or centre of motion D. For if a scale hangs at A, the extremity of the shorter arm, AB, is of such a weight as will exactly counterpoise the longer arm BC; if this arm is divided into as many equal parts as it will contain, each equal to AB, the single weight P (which we may suppose to be one pound) will serve for weighing any thing as heavy as itself, or as many times heavier as there are divisions in the arm BC, or any quantity between its own weight and that quantity. As for example, if P is one pound, and placed at the first division, one in the arm BC, it will balance one pound in the scale at A; if it is removed to the second division at two, it will balance two pounds in the scale; if to the third, three pounds; and so on to the end of the arm BC. If each of these integral divisions is subdivided into as many equal parts as a pound contains ounces, and the weight P is placed at any of these subdivisions so as to counterpoise what is in the scale, the pounds and odd ounces will by that means be ascertained.

To this kind of lever may be reduced several sorts of instruments, such as scissars, pincers, snuffers, which are made of two levers acting contrary to one another, their prop or centre of motion being the pin which keeps them together.

The second kind of lever has the weight to be raised between the prop and the power. Thus, in raising the water-plugs in the streets of London, you will see the workman put his iron crow through the hole of the plug till he rests the further extremity of it on the ground, and making that his prop, he raises the lever or crow, and draws out the plug. In this lever, as in the former, the longer the arm of the power is, or the greater the distance of the workman from the weight, the more is his natural force assisted by the machine. To estimate this, if AB (fig. 96.) is a lever on which the weight W of six ounces hangs at the distance of one inch from the prop G, and a power P equal to the weight of one ounce hangs at the end B, six inches from the prop, by the cord CD going over the fixed pulley E, the power will just support the weight; and a small addition to the power will raise the weight one inch for every six inches that the power descends.

This lever shows the reason why two men carrying a burden upon a stick between them, bear unequal shares of the burden in the inverse proportion of their distances from it. For it is well known, that the nearer any of them is to the burden the greater share he bears of it; and if he goes directly under it, he bears the whole. So if one man is at G, and the other at B, having the pole or stick AB resting on their shoulders; if the burden or weight W is placed five times as near to the man at G, as it is to the man at B, the former will bear five times as much weight as the latter. This is likewise applicable to the case of two horses of unequal strength to be so yoked, as that each horse may draw a part proportionate to his strength; which is done by so dividing the beam they pull, that the point of traction may be as much nearer to the stronger horse than to the weaker, as the strength of the former exceeds that of the latter.

To this kind of lever may be reduced oars, rudders of ships, doors turning upon hinges, cutting-knives which are fixed at the point of the blade, &c.

The third kind of lever is when the power is placed between the weight and the prop. An example of this kind of lever you see when a man raises a long ladder to place it against a wall. It is obvious that this kind of lever, so far from assisting human strength, requires a power much greater than the weight to be raised. For let E (fig. 97.) be the prop of the lever AB, and W, a weight of one pound, placed three times as far from the prop, as the power P acts at F by the cord C going over the fixed pulley

D; in this case the power must be equal to three pounds, in order to support the weight.

Disadvantageous as this kind of lever appears, it is upon this principle the human arm is constructed; for the muscle which moves the arm, and which is inserted in the bone below the elbow, may be considered as the power, which you see is placed between the weight to be raised by the hand and the prop, or place where the muscle is inserted above. To compensate for this disadvantage, these muscles are made unusually strong, and we may judge of their immense power by the weights which athletic persons are enabled to wield. The same power exerted only on equal terms ought to raise a weight of ten thousand pounds.

II. The *wheel* and *axle* (fig. 98.) is the next in order of the mechanic powers. The power is, in this machine, applied to the circumference of the wheel, and the weight to be raised is fastened to one end of a rope, of which the other end winds round an axle that turns with the wheel. This instrument is more commonly used with a handle: thus, to wind up a common kitchen jack, I turn the handle, which coils the cord round the axle in the middle: to wind a bucket from a well, I do the same thing; to wind up my watch, the same: the handle in all these is in the place of a wheel, and the farther this handle is from the centre, the axle, on which the whole weight is sustained, the more powerful will it be. Or if it is a wheel, the more its diameter exceeds the diameter of the axle, the greater will be its power. Thus, if the diameter of the wheel is eight times as great as that of the axle, it will have eight times the power; and a man who by his natural strength could only lift a hundred weight, by this machine will be enabled to lift eight hundred.

Of this kind are the machines called *cranes*, which you see employed at the water-side, for winding up bales of goods out of ships. The large circular crane, in which a man or horse walks and turns it horizontally, is also a machine of this nature; and the *capstan*, which draws up the cables of ships, and is turned by hand-spikes inserted in holes at the end of the roller or capstan. The *windlass*, also used in warehouses for raising goods, is the wheel and axle; and, indeed, many more complex machines may be resolved into this principle.

The spokes of the wheel, or the winch which turns the axle, may be considered as levers, and therefore by some the wheel and axle are referred to the same principle.

III. The *pulley* is usually considered as the third mechanic power, though, in truth, the single pulley AA (fig. 99.) gives no mechanical advantage, and only enables us to change the direction. This is evident from the figure, where the two equal weights W and P balance each other as exactly as the arms of a balance or scale beam, which are of equal lengths. Thus it gives a man no advantage, except that he can apply his weight as well as his strength in raising a body from the earth, and then he can lift more than his own weight.

With a combination of pulleys, however, the case is different. For if a weight W hangs at the lower end of the moveable pulley D, and the cord GF goes under the pulley, and is fixed at the top of the hook H on one side, and nailed to the block C on the other; it is evident that H and C between them support the whole weight W; H supports one half, and C the other half. Now suppose I take the support of one of their halves upon myself, but merely change the direction of my power, and instead of holding up the cord at C, throw it over the immoveable pulley fixed there, and exert my strength below at P; it will be evident that I support one half the weight W, and the hook H supports the other. If therefore I draw the cord at P, the weight W will continue to rise, but wherever it rises, I continue to support but half its weight while H supports the other. Thus, one single moveable pulley diminishes one half of the weight to be raised; if we should add another, it would diminish the half of that which remained, and so on. For instance, if a weight of eight hundred pounds is to be raised, I use one moveable pulley, and that will lessen the weight one half, that is, to four hundred: I add another moveable pulley, and that will lessen the remaining four by one half, which is two hundred; if I still add a third, that will lessen the remaining two by one half, which is one; so that if I use three moveable pulleys in raising eight hundred weight, I shall be able to raise it with as much ease as one hundred without them.

As systems of pulleys have no great weight, and lie in a small compass, they are easily carried, and can be used in many cases where more cumbrous engines cannot. They have much friction, however, because the diameter of their axis bears a very considerable proportion to their own diameter, because they are apt to rub against each other, or against the sides of the block, and because the rope that goes round them is never perfectly pliant. Still they are highly useful, and their combinations may be varied at pleasure, to suit the case in hand, whether at land or sea.

IV. The *inclined plane* is very justly regarded as the fourth mechanic power, though some have rejected it altogether. The advantage of this machine (if you will admit of that term) is, that by means of it a heavy body may be made to ascend a given height with much less power than it would require to raise it the same height if it were perpendicular. This is a very common mode of assisting human strength; you will every day see porters, when they have to roll a cask or bale up the step of a warehouse, place a board along from the step to the ground, which renders the ascent gradual and easy. The power of the inclined plane is as great as its length exceeds its perpendicular height. For instance, let AB (Pl. XXII. fig. 100) be a plane parallel to the horizon, and CD a plane inclined to it; and suppose the whole length CD to be three times as great as the perpendicular height AC; in this case the cylinder E will be supported upon the plane CD, and kept from rolling down upon it by a power equal to a third part of the weight of the cylinder. Therefore, a weight may be rolled up this inclined plane with a third part of the power which would be sufficient to draw it up by the side of an upright wall. If the plane were four times as long as high, a fourth part of the power would be sufficient; and so on, in proportion. Or, if a weight were to be raised from a floor to the height AC, by means of the machine ABCD, (which would then act as a half wedge, where the resistance gives way only on one side) the machine and weight would be *in equilibrio* when the power applied at AC was to the weight to be raised as AC to AB; and if the power is increased, so as to overcome the friction of the machine against the floor and weight, the machine will be driven, and the weight raised; and when the machine has moved its whole length upon the floor, the weight will be raised to the whole height from A to C.

V. The *wedge* is nearly allied to the inclined plane; indeed it may properly be considered as two equally inclined planes joined together. You know that its uses are to cleave or separate wood or stone, or any heavy bodies that adhere together. The power of the wedge is as its length to the thickness of its back. To show how we may calculate the force of a wedge, let *a* (fig. 101) be a wedge, which is interposed between the two cylinders *c* and *n*, which are pulled against the wedge by the two weights *r* and *s*, representing the resistance to be overcome by the force of the wedge. If then *r* and *s* influence the cylinders each with a force equal to two pounds, the resistance to be overcome will be equal to four pounds. Now the length of the wedge *a* is twice the thickness of its back, and the weight *o*, suspended to it, is two pounds. Here, then, is a resistance equal to four pounds overcome by a weight of two pounds, by means of a wedge, the length of which is double the thickness of its back. This explains sufficiently what a wedge will be able to effect by simple weight or pressure; but we see every day, where a hard stone or a piece of tough wood is to be cleft by a wedge, that a ton weight would not force it in, when a smart stroke of a hammer, which has not a fortieth part of that weight, will effect it at once. In this case we are to have recourse to what was said in the last lecture on the momentum or force which is gained by the velocity of a moving body, and consider that the momentum of a hammer consists of its weight multiplied by the velocity with which it moves (which is considerable), and then the effect will appear less extraordinary. It is by means of the momentum of the hammer striking with considerable velocity, that the wedge is driven in; and then its friction keeps it from slipping out again.

VI. The *screw* (fig. 102) may properly be considered as an inclined plane wrapt round a cylinder. The power of the screw is therefore as the length of each spiral or thread is to its height, or, in other words, as the circumference of the threads to their distance from one another. The screw, however, can only be wrought by means of a handle or winch, which is, in fact, a *lever*, and it may, therefore, be regarded as a compound machine. To estimate its force, then, let us suppose that I desire to screw down the press G upon B; every turn I make once round with both handles, I shall drive the press only one spiral nearer to B; so that if there are eleven spirals, I must make eleven turns of the handles, FL, before I come to the bottom. In pressing down the screw, therefore, I act with a force as much superior to the resistance of the body I desire to press, as the circumference of the circle, which my hands describe in turning the machine, exceeds the distance between two little spirals of the screw. For instance, suppose the distance between the two spirals to be half an inch, and the length of both handles twelve inches. My hands placed upon them in going round will describe a circle, which, upon calculation, will be found to be seventy-six inches nearly, and consequently this will be an hundred and fifty-two times greater than half an inch, which was the distance between two of the spirals. Thus, if a body is to be pressed down with this machine, one man will press it, with this assistance, as much as an hundred and fifty-two men without it. Or if the screw were so contrived as to raise the weight instead of pressing it, which sometimes is the case, the human force would be assisted in the same proportion with the same instrument. But we here only speak as if the handles of the screw were but twelve inches across, and the spirals a whole half inch distant from each other; what if we suppose the handles ten times as long, and the spirals five times as close; the increase of the human force then would be astonishing.

The power of the screw may, however, be still more correctly estimated by what is called the perpetual screw. To explain this, let the wheel C (fig. 103) have a screw *ab* on its axle, working in the teeth of the wheel D, which suppose to be forty-eight in number. It is plain, that for every time the wheel C and screw *ab* are turned round by the winch A, the wheel D will be moved one tooth by the screw; and, therefore, in forty-eight revolutions of the winch, the wheel D will be turned once round. Then, if the circumference of a circle described by the handle of the winch A is equal to the circumference of a groove *e* round the wheel D, the velocity of the handle will be forty-eight times as great as the velocity of any given point in the groove. Consequently, if a line goes round the groove *e*, and has a weight of forty-eight pounds hung to it below the pedestal EF, a power equal to one pound at the handle will balance and support the weight. To prove this by experiment, let the circumferences of the grooves of the wheels C and D be equal to one another; and then if a weight of one pound is suspended by a line going round the groove of the wheel C, it will balance a weight of forty-eight pounds hanging by the line *g*; and a small addition to the weight H will cause it to descend, and so raise up the other weight.

If the line *g*, instead of going round the groove *e* of the wheel D, goes round its axle I, the power of the machine will be as much increased as the circumference of the groove *e* exceeds the circumference of the axle: which, supposing it to be six times, then one pound at H will balance six times forty-eight, or two hundred and eighty-eight pounds hung to the line on the axle; and hence the power or advantage of this machine will be as two hundred and eighty-eight to one. That is, a man who, by his natural strength, could lift a hundred weight, will be able to raise two hundred and eighty-eight hundred weight, or 14 tons 8 hundred, by this engine.

But the following engine is still more powerful, on account of its having the addition of four pulleys; and in it we may look upon all the mechanical powers as combined together, even if we take in the balance. For as the axle D of the bar AB (fig. 104) enters its middle at C, it is plain that if equal weights are suspended upon any two pins equi-distant from the axis C, they will counterpoise each other. It becomes a lever by hanging a small weight P upon the pin *n*, and a weight as much heavier upon either of the pins *b*, *d*, or *e*, as is in proportion to the pins being so much nearer the axis. The wheel and axle FG is evident; so is the screw E which takes in the inclined plane, and with it the half wedge. Part of a cord goes round the axle, the rest under the lower pulley K, over the upper pulley L, under *k*, over *l*, and then it is tied to a hook at M in the lower or moveable block, on which the weight W hangs.

In this machine, if the wheel F have thirty teeth, it will be turned once round in thirty revolutions of the bar AB, which is fixed on the axis D of the screw E: if the length of the bar be equal to twice the diameter of the wheel, the pins *e* and *n* at the ends of the bar will move sixty times as fast as the teeth of the wheel do;

and, consequently, one ounce at P will balance sixty ounces hung upon a tooth *q* in the horizontal diameter of the wheel. Then if the diameter of the wheel F be ten times as great as the diameter of the axle G, the wheel will have ten times the velocity of the axle; and therefore one ounce P at the end of the lever AB will balance ten times sixty, or six hundred ounces hung to the rope H which goes round the axle. Lastly, if four pulleys are added, they will make the velocity of the lower block K, and weight W, four times less than the velocity of the axle; and this being the last power in the machine, which is four times as great as that gained by the axle, it makes the whole power of the machine four times six hundred, or two thousand four hundred. So that if a man could lift one hundred weight in his arms by his natural strength, he would be able to raise two thousand four hundred times as much, or 120 ton weight, by this engine. But it is here as in all other mechanical cases; for the *time lost is always as much as the power gained*, because the velocity with which the power moves will ever exceed the velocity with which the weight rises, as much as the intensity of the weight exceeds the intensity of the power.

The friction of the screw itself is very considerable; and there are few compound engines which will not, upon account of the friction of the parts against one another, require a third part more of power to work them when loaded, than what is sufficient to constitute a balance between the weight and the power.

Some philosophers have considered the wheel and axle, and the system of pulleys, as only modifications of the lever; and the wedge and the screw as modifications of the inclined plane. If this be admitted, we shall then have, instead of six, only two mechanical powers. The modifications and combinations of these are, however, almost endless, and wonders are performed, when to these means of increasing force are added the most powerful agents in nature, wind, water, and steam, as exemplified in the windmill, the water-mill, and, above all, the steam-engine. If the simple and obvious principles I have here elucidated shall assist the student in estimating the advantage of the more common machines, and stimulate him to pursue his researches into the manner of operation of the more complex engines to which I have just adverted, these explications will not have been given in vain.

LECTURE XVII.

ASTRONOMY.

SYSTEM OF THE UNIVERSE.

ASTRONOMY is that science which treats of the heavenly bodies.

It is by means of this science that we know the movement of those bodies, the duration of their revolutions, whether apparent or real, their position, their respective distances, &c.

The origin of astronomy is very obscure, and appears to be also very antient. "There is no doubt," says Cassini *, "but that astronomy was known almost from the beginning of the world. It was not only curiosity which led man to the study of astronomy, but it may be said that necessity itself obliged him to it. For if he did not observe the seasons which result from the apparent changes of the sun's place, it would be impossible to succeed in the practice of agriculture and other useful arts."

Astronomy, even if it could be considered as useless to man, derives from its very nature a certain degree of dignity. But let it be remembered, that upon it navigation, geography, and chronology greatly depend. By its aid man passes the

* Memoirs of the Academy of Sciences, vol. viii. page 1.

seas, and penetrates into foreign climates, becomes acquainted with those which he inhabits, and regulates the dates of ages past.

Hipparchus laid the principal foundations of a methodical system of astronomy one hundred and forty-seven years before Christ. On the appearance of a new fixed star, he took occasion to make a general catalogue of the stars, assigning to each its place in the heavens, and its magnitude, so as to enable posterity to ascertain, whether any new star had appeared, or any of those which he had observed had suffered any change. Ptolemy, about two hundred and eighty years afterwards, added his observations to those of Hipparchus; and by the natural advantage which he possessed over his predecessor, he was enabled to rectify greatly the observations of the former philosopher. Ptolemy was the last of the Greeks who made any considerable improvements in the science of astronomy. It was afterwards cultivated by the Arabians with great assiduity and success, but did not meet with any encouragement in Europe till about the middle of the 13th century. At this period Alphonsus the Tenth, king of Castile, became its zealous patron, and immortalized himself by a series of astronomical tables, which were published under his direction, and were distinguished by the name of the Alphonsine tables.

It was not, however, till the sixteenth century that astronomy was placed upon its proper basis as a science, by the system of Copernicus*, published at Nuremberg in 1543, and afterwards brought to perfection by Kepler, Galileo, and Newton:—a system so bold and daring, that it produced general astonishment, and yet its truth has been confirmed by the observations of every succeeding age.

The surface of the heavens seems to us to be studded with stars; between the fixed stars and us there seem to be other stars which change their situations respectively one towards another, and these all astronomers have agreed in calling *planets*, or wandering stars.

The antient philosophers, who knew very little even of the movements of the planets, had no means of knowing the true disposition of their orbits; and this is the reason they vary so greatly in their opinions. They supposed, at first, the earth to be immoveable, as the centre of the universe, and that all the celestial bodies turned about her; which, indeed, was natural for them to believe, without having discussed the proofs to the contrary.

It is asserted, however, that the Babylonians, and afterwards Pythagoras and his disciples, considered the earth as a planet, and the sun as immoveable, and the centre of our planetary system.

Plato is said to have been the reviver of the system of the immobility of the earth; and many

* Born at Thorn, in Royal Prussia, in 1472.

philosophers followed his opinion; among others was Claudius Ptolemy, the celebrated astronomer and mathematician of Pelusium in Egypt, already mentioned, who lived in the beginning of the second century of the christian æra. It is, however, incredible that, the true system of the world having been once discovered, the hypothesis by which the earth is supposed to be the centre of the celestial movements should have again prevailed; for though this hypothesis accords with some of the most obvious appearances, and seems to agree at first with the simplicity of nature, yet it is impossible on that system to account for all the celestial phænomena.

Ptolemy, who has given the name to this system, endeavours to prove that the earth T (Pl. XXIII. fig. 105) is immoveable as the centre of the universe; and he places the other planets round about her in the following order, beginning with those which he believes the next to the Earth: the Moon ☽, Mercury ☿, Venus ♀, the Sun ☉, Mars ♂, Jupiter ♃, and Saturn ♄, till he comes at length to the fixed stars. When, however, astronomers had begun to observe the planets, they remarked that Mercury and Venus are sometimes nearer and sometimes farther from us than the Sun; and that Venus never departs from the Sun more than about forty-seven degrees and a half; and Mercury about twenty-eight degrees and a half, and sometimes much less. But it is evident that if these two planets were turned about the Earth, as they supposed the Sun himself turned, they would sometimes appear opposite to the Sun, or more distant from him than one hundred and eighty degrees; which never happens. This is the reason why the Egyptians regarded these two planets as satellites of the Sun, and thought that they turned about him, their orbits being carried with him in his revolutions about the Earth. They therefore supposed the Earth T (fig. 106) immoveable, as the centre of the system; and they supposed the other celestial bodies to turn round her: first, the Moon ☽; secondly, the Sun ☉; about which they made Mercury ☿ and Venus ♀ to revolve, till they came to Mars ♂, Jupiter ♃, and to Saturn ♄; and lastly to the fixed stars.

At the present day, however, when we know the immense distance at which the stars are placed, both these systems become insupportable. They require that all the heavenly bodies should go through the whole course of their orbits in about 24 hours, which would give to the fixed stars a rapidity of motion that exceeds all belief:—nay, the Sun himself would in a single second have to describe a space of more than two thousand five hundred miles.

Copernicus, with a view of obviating the inconveniences of the imaginary systems that preceded him, commenced at first by admitting the diurnal motion of the Earth, or her motion round her own axis, which rendered useless that prodigious celerity in the motions of the heavenly bodies, of which I have just spoken, and by these means simplified the system. This motion once admitted, it was no violent step to admit of a second motion of the Earth in the ecliptic. These two motions explain, with the utmost facility, the phænomena of the stations and motions of the planets. According to Copernicus, then, the Sun S (Pl. XXIV. fig. 107) is the centre of our planetary system, and the planets turn about him in the order following; Mercury ☿, Venus ♀, the Earth ♁, Mars ♂, Jupiter ♃, Saturn ♄, (to which we may add Ceres, Pallas, Juno, Vesta, and the Georgium Sidus ♅) at a distance from the Sun, nearly as the numbers 4, 7, 10, 15, 52, 95, 191. The Moon, also, he supposed to be carried round the Earth in an orbit which goes along with the Earth in her annual revolution round the Sun. In like manner about Jupiter, Saturn, and the Georgium Sidus, are the four satellites of the first, the five satellites of the second, and the two satellites of the third; none of which, however, were known to Copernicus.

Although the celestial phænomena explain themselves with the greatest facility according to the system of Copernicus, and though observation and reason are equally favourable to it, yet it was rejected by an able astronomer who flourished soon after his own time. Tycho-Brahe, from the experiment that a stone thrown from a high tower fell at its foot, argued that the Earth must be without motion, never reflecting that the Earth, in that case, is like a vessel in full sail, when if a stone is thrown from the mast, it would fall at the foot of that mast, provided the motion of the vessel was neither accelerated nor retarded during the fall. Tycho-Brahe, therefore, invented a system between that of Ptolemy and that of Copernicus. He supposed that the Earth was at rest, and that the other planets revolving round the Sun, turned also with him round the Earth in twenty-four hours. It was towards the end of the sixteenth century that he proposed his system. He placed the Earth (fig. 108) immoveable, as the centre, and made the Moon turn round her, as well as the Sun S, and the fixed stars: the other planets, viz. Mercury, Venus, Mars, Jupiter, and Saturn, turning round the Sun, in orbits which are carried with him in his revolution round the Earth. As the system of Tycho-Brahe requires the same rapidity of motion as that of Ptolemy and of the Egyptians, it is at once annihilated by the same arguments.

Leaving, however, for the present the history of astronomical discoveries, I shall request your attention to the celestial phænomena.

There are evidently two sorts of stars; the one luminous of themselves, and throwing light on every object which surrounds them to a certain distance; such as our Sun, and those which we call fixed stars. The others are opake bodies, as the Earth which we inhabit, not luminous of themselves, but which shine by a borrowed light; in few words, luminous by reflecting that light which comes from a luminous star: such are the planets of the first and second order, and the comets.

The stars of the firmament are said to be fixed, because they have been generally observed to preserve the same distance from each other: they do not all appear to us of the same magnitude, whether they are really different in size one from the other, or whether they appear so to us in consequence of their different distances. It is probable that both these causes operate to exhibit the fixed stars of such various magnitudes. Be this as it may, astronomers have agreed in distributing the fixed stars into six different classes, according to their relative magnitude, independent of those small stars which compose the white and brilliant spaces in the heavens, which are denominated nebulæ, and that bright band which extends across our hemisphere, and which from its lucid appearance is termed the milky way. Those which are distinctly visible are fewer in number than might be supposed. The British catalogue, which, besides the stars visible to the naked eye, includes a great number which cannot be seen without the assistance of a telescope, contains no more than three thousand in both hemispheres. The number of stars discoverable, in either hemisphere, by the naked eye, is not above a thousand. From what we are able to judge by computation and observation, it is concluded that none of the fixed stars can be at a less distance than 32,000,000,000,000 of miles from us, which is further than a cannon-ball would fly in 7,000,000 of years. The famous French astronomer Lalande, indeed, makes the distance by a late computation to be 7,086,760,000,000 leagues.

Though the number of the fixed stars is less than common observers might imagine, yet it is still too great, from their resemblance to each other, to enable us to distinguish them by giving each a particular name, as has been done with regard to the planets. Astronomers therefore have found a commodious method of arranging them under various figures, called *constellations.* They have given to these constellations the names and figures of various personages celebrated in antiquity, and even of many animals or of inanimate bodies, as instruments, machines, &c. which fable has feigned to have been carried from earth to heaven. Ptolemy has enumerated forty-eight constellations; and there are upon our globes about seventy. On Senex's, Jones's, and Cary's globes Bayer's letters are inserted*; the first in

* In the best of Jones's and Cary's globes, the double, triple, quadruple, and nebulous stars are indicated by appropriate characters.

the Greek alphabet being put to the largest star in each constellation; the second to the next, and so on; by which means every star is as easily found as if a name were given to it. Thus if the star α, in the constellation of the *ram*, is mentioned, every astronomer knows as well what star is meant, as if it were pointed out to him in the heavens.

The constellations which surround the ecliptic, or apparent annual path of the Sun, and which fill that zone of the heavens which is called the zodiac, are the twelve following:

Aries, or the ram, ♈
Taurus, the bull, ♉
Gemini, the twins, ♊
Cancer, the crab, ♋
Leo, the lion, ♌
Virgo, the virgin, ♍
Libra, the balance, ♎
Scorpio, the scorpion, ♏
Sagittarius, the archer, ♐
Capricornus the goat, ♑
Aquarius, the water-bearer, ♒
Pisces, the fishes, ♓.

The zodiac goes quite round the heavens; it is about sixteen degrees broad, so that it takes in all the orbits of the old planets, and likewise the orbit of the Moon.

After having divided the ecliptic into twelve equal parts, which are each thirty degrees, they have assigned a mark to each of these distances, and they have given to it the name of the constellation which it contained. The first of these signs begins always at the point of intersection of the ecliptic with the equator, in which the Sun is found at the vernal equinox.

The twenty-one constellations enumerated by Ptolemy in the northern part of the heavens are,

Ursa minor,	the little bear.
Ursa major,	the great bear.
Draco,	the dragon.
Cepheus.	
Bootes.	
Corona Borealis,	the northern crown.
Hercules,	Hercules kneeling.
Lyra,	the harp.
Cygnus,	the swan.
Cassiopeia,	the lady in her chair.
Perseus.	
Auriga,	the waggoner.
Serpentarius.	
Serpens,	the serpent.
Sagitta,	the arrow.
Aquila,	the eagle.
Delphinus,	the dolphin.
Equulus,	the horse's head.
Pegasus,	the flying horse.
Andromeda.	
Triangulum,	the triangle.

The fifteen constellations described by Ptolemy towards the southern part of the heavens are,

The whale.	The cup.
Orion.	The crow.
Eridanus, the river.	The centaur.
The hare.	The wolf.
The great dog.	The altar.
The little dog.	The southern crown.
The ship.	The southern fish.
The hydra.	

The stars which could not be comprehended in these constellations were called *unformed* stars; but several new constellations have been made out of them by the moderns. The following have been added to the northern constellations:

The camelopard.	The lizard.
The greyhounds.	The little triangle.
The little lion.	Cerberus.
The lynx.	Mountain Menalus.
The fox and goose.	The fly.

Those which follow have been added to the constellations in the southern hemisphere:

Noah's dove.	The phœnix.
The unicorn.	The sword-fish.
The cross.	The flying fish.
The sextant.	The water-snake.
Sobeiski's shield.	The cameleon.
The royal oak.	The fly.
The peacock.	The bird of Paradise.
The crane.	The south triangle.
The American goose.	The Indian.

Notwithstanding these additions, there yet remain in this hemisphere a very great space, and a great number of unformed stars, of which the Abbé de la Caille, a very learned and a very laborious astronomer, has formed fourteen new constellations, which he has dedicated to the arts, in giving them the figures and the names of the principal instrument. The following is the list of these, in the order of their right ascension:

The carver's workshop.	The air-pump.
The chemical stove.	The octant.
The clock.	The compass.
The rhomboid reticule.	The square and ruler.
The graver.	The telescope.
The painter's easel.	The microscope.
The mariner's compass.	The mountain near Table Bay.

I have already noticed that there is a remarkable track round the heavens, called the *milky way,* from its peculiar whiteness, which is found, by means of the telescope, to be owing to a vast number of very small stars that are situated in that part of the heavens. There are also several little whitish spots which appear magnified, and more luminous when seen through telescopes, yet without any stars being distinguishable in them. One of these is in Andromeda's girdle, and was first observed in the year 1612 by Simon Marius; it has some whitish rays near its middle, is liable to several changes, and, according to some astronomers, occasionally disappears. Another is near the eliptic, between the head and bow of *Sagittarius;* it is small but very luminous. A third is on the back of the *Centaur*, which is too far south to be seen in Britain. A fourth, of a smaller size, is before Antinoüs's right foot, having a star in it, which makes it appear more bright. A fifth is in the constellation of *Hercules*, between the stars ζ and η, which spot, though but small, is visible to the naked eye, if the sky is clear, and the Moon absent. It is also found that several of the stars, which appear single to the naked eye, are double, triple, or even quadruple, when viewed through a good telescope. Dr. Herschell and other astronomers have classified these.

Dr. Herschell has discovered other appearances in the heavens, which he calls nebulæ or cloudy stars. They are stars surrounded by a faint luminous substance of a considerable extent. What the nature of this substance may be we cannot easily conjecture, but the phænomenon is certainly very curious and interesting *.

* Before I proceed any further in explaining the solar system, it seems proper to make the student acquainted with the principal words and phrases which are appropriated to this science.

The *poles* are the extremities of the axis on which the globe turns.

The *globe* or *sphere* is divided into two equal halves or hemispheres by one great circle, perpendicular to the axis, which for that reason is called the equator or equinoctial.

The *sensible horizon* is a circle which separates the visible from the invisible hemisphere, or that which is the boundary of our sight, and which seems to bring the apparent arch of the heavens in contact with the earth.

The *rational horizon* is a great circle, parallel to the former, but which would divide the globe into equal portions.

A *parallel sphere* is so called because under it the equator coincides, or is parallel to the horizon. The poles are in the zenith and nadir; that is, one pole is directly over the head of the spectator, and the other directly under his feet. The inhabitants of this sphere would be those, if it were habitable (which, however, we may venture to decide in the negative, from the extreme cold), that lived under the poles, who could have but one day and one night in the year. The day continues six months while the sun appears to pass through six signs of the zodiac, and the night six months, while he appears to pass through the other six. The day, under the north pole, begins when the sun enters aries, and continues till he reaches libra; when night commences, and continues the other six months.

Under the south pole the direct contrary happens, it being day there when it is night in the former situation, and the contrary. But at both the poles there is a long continuance of twilight, both after the sun has departed, and before he appears.

The polar inhabitants (if there are any) see the sun for half the year, moving continually round above the horizon, in a spiral line; the first round skimming the skirts of the horizon; the second, higher; and so on, till, by ninety revolutions, he has reached the tropic, his utmost declination; after which, by ninety more revolutions, he again reaches the horizon, and then long winter night begins.

A *right sphere* is so called, because under it the equator cuts the horizon at right angles. The poles will lie or be in the horizon. The equator will be in the zenith and nadir.

The inhabitants of this sphere are those who live under the equinoctial line, and have their days and nights always equal, viz. twelve hours each; because not only the equator but also all the parallels of latitude are cut into two equal parts by the horizon. And therefore, as the sun's diurnal arches are equal to the nocturnal, each day must be equal to the night, viz. twelve hours each. The sun rises and sets nearly in a vertical direction. He comes to the meridian with the same degree of the equator with which he rose; and hence there can be no ascensional difference. He is half a year on one side of their zenith, and as much on the other; passing over their zenith but twice a year, viz. at the equinoxes.

An *oblique sphere* is so called because in it the equator cuts the horizon obliquely. This position of the globe is common to all the inhabitants of the earth, except those who are situated under the poles, and under the equinoctial. The properties of this sphere are as follow: the pole is elevated to any degree less than ninety, the axis of the earth always making an acute angle with the horizon. All the parallels to the equator cut the horizon obliquely, making the diurnal greater or less than the nocturnal arches; and consequently producing an inequality in the days and nights, which are never equal but when the sun is in aries and libra, which happens in March and September, when he moves in the equator, making equal days to all the inhabitants of the earth, except those under the poles. The inhabitants of this sphere, who live without the tropics, never have the sun in their zenith, but under the tropics he is vertical once, and between the tropics and the equator twice, every year. The stars rise and set obliquely in this position; and the nearer the observer is situated to the equator, the greater number of them will be visible. The length of the twilight is longer or shorter in this position, according as the latitude is greater or less.

The *Antœcii*, or Antœcians, are those inhabitants of the globe, who have the same longitude with us, but are as far to the south of the equator as we are to the north. Their hour is the same as ours, it being noon, &c. with both at the same time. Their days are equal to our nights, and the contrary. And their summer is our winter.

The *Periœcii*, or Periœcians, are those that lie under the same parallel of latitude with us, on the same side of the equator, only are distant one hundred and eighty degrees of longitude, viz. a semicircle.

They have contrary hours, it being noon with them when it is midnight with us. Their days and nights are of the same length with ours. Their season or time of the year is also the same as with us.

The *Antipodes* are such inhabitants as have the same latitude south as we have north, but differ one hundred and eighty degrees in longitude; that is, they and we have opposite parallels and opposite meridians. Their hour is directly the reverse of ours, it being noon with them when it is midnight with us. Their longest day is our shortest day, and their longest night our shortest night. The four seasons are contrary, their summer being our winter, &c. They are called Antipodes because their feet are opposite to our feet; that is, they go with their heads downwards in respect of us.

The *Amphiscii* are so called because their shadows are cast different ways at noon at different times of the year; that is, their shadow sometimes points to the north, and sometimes to the south: therefore it is easy to perceive that these people live in the torrid zone, that is, between the tropics.

A *great circle* is one the plane of which passes through the centre of the spheres.

A *secondary* to a great circle of the sphere is a great circle passing through its poles.

The *angular distance* of a heavenly body from a great circle is an arch of the secondary to the great circle passing through the body and intercepted between it and the great circle.

Altitude is the *angular* distance of a heavenly body from the horizon. The meridian altitude of the sun is the height of it from the horizon at twelve o'clock.

Declination is the angular distance of any heavenly body from the equinoctial or equator, and is called north or south, according to the side of the equinoctial on which the declination is.

Right ascension is an arch of the equinoctial contained between the first of aries ♈ and the point of it that is cut by a secondary to the equinoctial passing through the heavenly body.

Oblique ascension is that arch of the equinoctial which is contained between the first of aries and the point of the equinoctial which is cut by the horizon at the rising of the heavenly body.

Ascensional difference is the difference of degrees between the right and oblique ascension, which converted into time, by allowing fifteen degrees for every hour, shows how much the sun or star rises or sets before or after six; that is, subtract the less from the greater number, and the remainder will give the ascensional difference.

Amplitude is an arch of the horizon contained between the true east or west points and that point of the horizon where the heavenly body rises or sets, and is called north or south amplitude accordingly.

Azimuth is an arch of the horizon intercepted between the north or south points and that point of the horizon to which the heavenly body is referred by a secondary passing through it.

Almacanthers are less circles parallel to the horizon.

The *latitude* of a heavenly body, is its angular distance from the ecliptic, and is called north or south latitude according as the body is on the north or south side of the ecliptic.

The *longitude* of a heavenly body is an arch of the ecliptic intercepted between the first of aries and the point of it, which is cut by a secondary to the ecliptic passing through the heavenly body.

The *armillary sphere* is an instrument composed of the principal circles which are usually drawn upon an artificial globe.

The *colures* are two secondaries to the equinoctial; the one passing through the equinoctial points, and called the equinoctial colure, the other passing through the solstitial points, and called the solstitial colure.

The *ecliptic* is 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. This angle varies within very narrow limits.

The *equinoxes* are 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 all over the globe.

The *geocentric place* of a planet is that position which it has when seen from the earth, or, strictly from the earth's centre.

The *terminator* is that great circle which divides the enlightened hemisphere from the dark hemisphere of any planet.

The *heliocentric* place of a planet is that in which it would appear to a spectator placed in the sun's centre.

The *sextile* is an aspect of two heavenly bodies when they are sixty degrees distant from each other, and is denoted in an ephemeris by ✱.

Trine is an aspect of two planets when they are a hundred and twenty degrees distant from each other, and in an ephemeris it is denoted by △. In like manner *quartile*, marked □, is when two heavenly bodies are 90° asunder in longitude; *opposition*, marked ☍, when they are 180° asunder; and *conjunction*, marked ☌, when two heavenly bodies have the same longitude. Thus at the time of *new moon*, the sun and moon are in ☌; at the time of *full moon* they are in ☍; and in the first and last quarters they are in □ or quartile aspect. These aspects for all the planets are shown in Partridge's Almanac.

The diurnal *Parallax* of a heavenly body is the angular distance between the places of the body, when referred to the heavens, as seen from the centre and the surface of the earth; or it is the angle which the earth's radius would subtend at the heavenly body.

The annual *Parallax*, or the parallax of the earth's orbit, is the angular distance between the different places of the body as seen from opposite points of the earth's orbit.

Apogé is that point of the orbit of a planet or the imaginary orbit of the sun which is farthest from the earth.

Perigé is that point in the orbit of a planet, &c. when it is nearest to the earth.

Aphelion is the point of an orbit most distant from the sun.

Perihelion is that point of an orbit, whether planetary or cometary, which is nearest the sun.

LECTURE XVIII.

ASTRONOMY.

OF THE SUN, AND HIS REAL AND APPARENT MOTIONS.

THE sun with the planets and comets which move round him as their centre constitute what is called the solar system. Those planets which are near the sun not only finish their circuits sooner, but likewise move faster in their respective orbits than those which are more remote from him. Their motions are all performed from west to east in orbits nearly circular, but in truth elliptical, except so far as they are effected by each other's disturbing forces.

The sun, the centre of the system, has been generally considered as composed of the matter of light and heat, whether these are to be regarded as essentially the same or not; perhaps it will be speaking more correctly to say, that he is the source of both, and that he both warms and enlightens the bodies which surround him, probably by means of perpetual emanations from a luminous atmosphere. The sun has two apparent motions, the *diurnal* and the *annual*. In the first he appears to revolve round the earth in the course of a solar day, or about 24 hours; by the other he appears to traverse that circle in the heavens which is called the ecliptic, in the course of the solar year. It is almost unnecessary to tell you that neither of these motions is real. For the first depends upon the earth's rotation on its own axis, and the second on her annual revolution round the sun. This deception of our senses with respect to the sun and heavenly bodies appearing to move, may be compared to that which we experience, when sailing in a vessel within sight of the shore, when the trees and villages appear all moving in a contrary direction, and we ourselves to remain at rest.

But though the vulgar language of astronomy is thus, as M. Voltaire observes, a tissue of falsehood, it yet conveys no deception to those who are once acquainted with the true principles. Thus, though we know that the sun does not change his place in the heavens, and that it is the earth only which moves, yet it is no absolute solecism to say that the sun is in aries, or any other point of the heavens; for with respect to us he is to all intents and purposes apparently there. To make this clear by a very easy diagram: Let us for a moment suppose the earth the centre of the system at S, (Pl. XXV. fig. 109.) and the sun to revolve round it in the orbit ABCD; and let EFGH represent what appears to us the concave sphere of the starry heavens. As the sun moves in this supposed orbit, when he is at A he will appear to a spectator at S to be at E among the fixed stars, when at B he will appear at F, when at C at H, &c.

Now let us reverse the supposition, and consider the place of the sun as it really is at S, and let us regard ABCD as the earth's orbit, and we shall find the result substantially the same as to the appearance of the sun in the heavens. That is, when the earth is at A, the sun will appear among the stars at H; when at B, the sun will appear at G; when at C, the sun will be at E. Though the sun therefore does not in reality change his place, you must perceive that to a spectator on the earth he will in fact appear to describe the same circle EFGH in the starry heavens, as if he had been the moving body instead of our earth.

The earth's orbit being an ellipsis, the sun is not always at equal distances from it. When in his apogé, the sun is about 1171468 leagues further from us than when in his perigé. In this last case then not only must he subtend a greater angle, but it would *appear* that we should derive from him a greater degree of heat. The difference of temperature between summer and winter does not, however, depend solely on our proximity to the sun or our distance from him, though this cause is not without its influence; for in truth the sun is in his apogé in our summer, and in his perigé in winter. The heat of summer depends chiefly on three other causes.

1st. In summer the solar rays strike less obliquely upon the earth than in winter; and it may be demonstrated on the principles of mechanics, that a body which acts perpendicularly upon another acts with all its force; whereas if it acts obliquely, its force is less in proportion to the degree of the obliquity. The rays of light follow the same laws as other bodies, and consequently their action might be measured by the sine of their angle of incidence. There is no necessity for a diagram to explain what is now laid down, since it is obvious that as the equator divides the earth into two equal parts, when the sun is on this, that is, the north side of it (as he is in summer) his rays must strike more vertically, or more in the perpendicular line, than when he is in the southern tropic. 2d. In summer also, the rays falling more vertically, have less of atmosphere to pass, and that atmosphere is usually less clouded. 3d. In summer the sun continues a longer time above the horizon than below it; and consequently there is time for the earth to accumulate a greater portion of heat than in the days of winter.

Since the sun is further from us in summer than in winter, it follows that the inhabitants of the opposite (the southern) hemisphere must have (all other circumstances equal) more heat during their summer, and more severe cold during their winter, than we have; and this is found to be the case.

In the last lecture I mentioned the signs of the zodiac, or those which the planets traverse in their revolution about the sun, and through which the sun himself *apparently* passes in consequence of the annual revolution of the earth. To these 12 signs the names of the 12 constellations of the zodiac are given; we must, however, not confound these signs in the heavens with the constellations which bear these names. In the time of Hipparchus the sign and the constellation were nearly the same, and each of the constellations occupied with sufficient exactness that 12th part of the zodiac which bore its name. But at present this is not the case; the *sign* Aries, which is the first, denotes the first portion or 12th part, that is, the first 30 degrees on the circle of the ecliptic, counting from that point where that circle intersects the equator; but the *constellation* Aries is an assemblage of stars which formerly corresponded with the place of the sign, but which is now advanced about 30 degrees, so that in fact the constellation Aries now occupies the place of Taurus; Taurus that of Gemini, &c.

The first point of the zodiac, or, as it is called, the first point of Aries, is at the point where the equator intersects the ecliptic. It is from this point that astronomers begin to count the longitude of the fixed stars; and this point also constitutes the vernal equinox. This point, however, is found to recede westward every year about 50 seconds of a degree. The fixed stars, of course, appear to have advanced every year in the same proportion, by a movement which is general and common to all, about the poles of the ecliptic. Their longitude is therefore annually augmented in this proportion.

This general movement of the fixed stars, and this difference of longitude, depend upon what is called the precession of the equinoctial points; and this precession, physical astronomers say, is produced by the modified attractions of the sun and moon upon the spheroidal figure of the earth, which is known to be not a perfect globe, but rather flatted at the poles. By means of these attractions acting more powerfully upon the equatorial regions, the poles of the equator describe circles about the poles of the ecliptic, in the long period of 25,748 years. Hence, if the sun is one year in conjunction with a particular star at the instant of the equinox, he ought the succeeding year to be at the equinox before he comes in conjunction with the same star. The arrival of the sun at the equinoctial point therefore *precedes* the termination of his revolution, and hence is derived the phrase *the precession of the equinoxes.* The complete explication of this interesting phenomenon is too recondite to admit of introduction into a popular treatise like the present. It is very well done, though not in an elementary manner, in Laplace's elegant *Systeme du Monde.*

The fixed stars appear every day to make an entire revolution round the earth. The sun, I have said, makes the same apparent diurnal revolution. But the diurnal motion of the sun is apparently slower than that of the fixed stars. It is almost needless to repeat to you that these appearances are caused by the daily rotation of the earth upon its axis, which is accomplished in 23 hours 56 minutes and 4 seconds. If, however, the earth only turned upon its axis; and if while it turned in this manner it did not advance in its orbit, the apparent diurnal movements of the sun and fixed stars would always be the same. The stars which had passed once over the same meridian with the sun would constantly repeat the same movement in the same time; the winter and the summer nights would at the same place present the same constellations. But because of the annual motion of the earth from west to east round the sun, in which it advances about 59 minutes and 8 seconds of a degree in a day, the sun appears to advance in the same proportion in the ecliptic. This constitutes the difference between solar and sidereal time, in explaining which I shall make use both of the figure and the words of Mr. Ferguson.

"Let ABCDEFGHIKLM be the earth's

orbit, (Pl. XXV. fig. 110.) in which it goes round the sun every year, according to the order of the letters, that is, from west to east; and turns round its axis the same way from the sun to the sun again in every 24 hours. Let S be the sun, and E (in fig. 109) a fixed star at such an immense distance, that the diameter of the earth's orbit is but a point in proportion to that distance. Let N *m* be any particular meridian of the earth, and N a given point or place upon that meridian. When the earth is at A the sun S hides the star E, which would be always hid if the earth never removed from A; and consequently, as the earth turns round its axis, the point N would always come round to the sun and star at the same time. But when the earth has advanced, suppose 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 natural day, or two hours, sooner to the star than to the sun, for the angle N B *n* is equal to the angle ASB: and therefore any star which comes to the meridian at noon with the sun when the earth is at A, will come to the meridian at 10 in the forenoon when the earth is at B. When the earth comes to C, the point N will have the star on its meridian at 8 in the morning, or four hours sooner than it comes round to the sun; for it must revolve from N to *n* before it has the sun in its meridian. When the earth comes to D, the point N will have the star on its meridian at 6 in the morning, but that point must revolve six hours more from N to *n*, before it has mid-day by the sun: for now the angle A S D is a right angle, and so is N D *n*; that is, the earth has advanced 90 degrees in its orbit, and must turn 90 degrees on its axis to carry the point N from the star to the sun: for the star always comes to the meridian when N *m* is parallel to R S A; because D S is but a point in respect to R S. When the earth is at E, the star comes to the meridian at 4 in the morning; at F, at 2 in the morning; and at G, the earth having gone half round its orbit, N points to the star R at midnight, it being then directly opposite to the sun. And therefore, by the earth's diurnal motion, the star comes to the meridian 12 hours before the sun. When the earth is at H, the star comes to the meridian at 10 in the evening; at I it comes to the meridian at 8, that is, 16 hours before the sun; at K 18 hours before him; at L 20 hours; at M 22; and at A equally with the sun again.

"Thus it is plain, that an absolute turn of the earth on its axis (which is always completed when any particular meridian comes to be parallel to its situation at any time of the day before) never brings the same meridian round from the sun to the sun again; but that the earth requires as much more than one turn on its axis to finish a natural day, as it has gone forward in that time; which, at a mean state, is a 365th part of a circle. Hence, in 365 days, the earth turns 366 times round its axis; and therefore, as a turn of the earth on its axis completes a sidereal day, there must be one sidereal day more in a year than the number of solar days, be the number what it will, on the earth, or any other planet, one turn being lost with respect to the number of solar days in a year, by the planet's going round the sun; just as it would be lost to a traveller, who, in going round the earth, would lose one day by following the apparent diurnal motion of the sun; and consequently would reckon one day less at his return (let him take what time he would to go round the earth) than those who remained all the while at the place from which he set out. So, if there were two earths revolving equally on their axes, and if one remained at A until the other had gone round the sun from A to A again, *that* earth which kept its place at A would have its solar and sidereal days always of the same length; and so would have one solar day more than the other at its return. Hence, if the earth turned but once round its axis in a year, and if *that* turn was made the same way as the earth goes round the sun, there would be continual day on one side of the earth, and continual night on the other."

The sun is unquestionably to us the most interesting of all the heavenly bodies. The heat which he diffuses animates our world, and his light is the source of all our purest pleasures. His power reaches to a most extended sphere, the more active in proportion to the nearness. Our water would be in a boiling state at Mercury, and frozen at Saturn. Yet the beings who exist in those worlds are undoubtedly accommodated to the climates they inhabit.

The sun is of a form nearly spherical. He however appears to us only as a circular disc. This is because all the parts of his surface are equally luminous; and consequently there is nothing which can suggest to us that the centrical parts are more prominent than the sides, though in reality they are nearer to us by 160,000 leagues. In the same manner the full moon appears to us a flat surface, but a good telescope corrects the deception.

So early as the year 1611 spots were discovered upon the disc of the sun. The discovery was claimed both by father Scheiner and by Galileo. These spots consist, in general, of a 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 the whole 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.

The speculations and opinions of philosophers concerning the nature and origin of the solar spots are various, and perhaps all erroneous, since we are in truth unacquainted with the materials of which his body is composed. One of the most popular conjectures 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 little torches. M. de la Hire 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. Nearly akin to this is the more recent hypothesis of Herschel, who supposes the sun to be itself opaque, but surrounded by a phosphoric or luminous atmosphere, beyond which the tops of mountains on the sun's body sometimes project, and appear to the telescopic observer as black spots.

Whatever may be the nature of these spots, the observance of them has produced a discovery of some importance. It was early observed that they ceased to be visible at certain intervals, and again at stated periods reappeared. The apparent motion of the spots is from the eastern to the western side of the sun; and as they are observed to move quicker when they are near the central region than when they are near the limb, it follows that the sun must be a spherical body, and that he revolves on his axis 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 time of the motion of the spots, which is sometimes straight, but more frequently curved 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, as it is called, is another striking phænomenon connected with this glorious luminary. In explaining it the sun is supposed to be enveloped with a fluid matter, luminous in itself, or only enlightened by the solar rays, and which constitutes a higher atmosphere. This matter is more abundant and more extended round his equator than elsewhere, and gives to the solar atmosphere an appearance resembling that of a double convex lens, the diameter of which is in the plane of the sun's equator. It was discovered in 1683, by

Cassini, who observed it for about 8 days. It has obtained the name of the zodiacal light, because it appears along the zodiac in the form of a lance or pyramid. It is of a faint whitish colour resembling the milky way.

The zodiacal light is more or less visible according to circumstances. It is most apparent when it has a sufficient extent along the zodiac, and when the obliquity of the zodiac to the horizon is not too great, for otherwise its faint light will scarcely be distinguished from the twilight, whether previous to the rising of the sun, or after his setting.

The zodiacal light appears generally in a conical form, having its base always directed towards the body of the sun, and its point towards some star in the zodiac. It is thus it appears in the evening in the spring, and in the morning in the autumn. Its eastern point being displayed in the evening, and its western in the morning. The two points may sometimes be seen in the same night, as at the solstices, and particularly at the winter solstice, when the ecliptic makes, in the evening and the morning, angles, almost equal with the horizon, and sufficient to leave a considerable part of the point above the line of twilight. The summer solstice has the disadvantage of the too great obliquity of the ecliptic with respect to the horizon, and of a long twilight.

In the evening and morning observations, only the superior parts of the phænomenon, with respect to the horizon of the observer, are apparent. For, as the sun rises and approaches the horizon, or again before he has descended many degrees below it, it becomes lost in the twilight. This circumstance is usually thus explained—Let IKOA (Pl. XXVI. fig. 111.) be the zodiacal light in one of the most favourable positions for observing it, that is about the latter end of February or beginning of March, when the first point of Aries may be supposed in K, upon the plane of the horizon HR, and the sun being in S, about the 10th degree of Pisces upon the boundary CP of twilight, 18 degrees below the horizon. The ecliptic TKZ is here confounded with the axis AZ of the zodiacal light, and forms with the horizon an angle of about 64 degrees. The point A of this light falls between the stars of the neck and head of Taurus, and terminates about the 10th degree of Gemini, whence it follows that the distance from its point to its base at the sun is about 90 degrees.

The same figure represents the situation AEZ which this light would assume, the morning of the same day just before day-break. The angle N *t z* of the ecliptic with the horizon being about 26 degrees, supposing only that the spectator, who had in the evening the north-pole B on his right, and the meridian M at his left, being turned towards the east, shall have on the contrary the north at his left, and the south at his right. It is plain, from what has been said, that the part of the zodiacal light which is near the sun cannot be seen upon the horizon, because the twilight will cause it to disappear, or at least render its borders very indistinct. It is only a total eclipse of the sun which can show it at the base, and in its densest part; in that case, as soon as the disc of the moon has completely obscured that of the sun, there appears round the moon an enlightened border, and a kind of beam; it is more or less dense, according to its distance from the edge of the moon.

The zodiacal light must be more easily and more frequently perceived in the tropical climates, and particularly near the equator, than it can here; first, because in those parts the obliquity of the equator and the zodiac to the horizon is less; and secondly, because the duration of the twilight is much shorter. This curious light was observed by Cassini in 1683; and there is reason to suspect that earlier astronomers observed it, but did not describe it with sufficient precision.

LECTURE XIX.

ASTRONOMY.

THE PRIMARY PLANETS; THE MODE OF CALCULATING THEIR DISTANCES, &c.

THE planets, I have already intimated, are opaque bodies, very nearly spherical, and we have reason to believe much like the earth. They are not luminous of themselves; and become visible only by reflecting the light which they receive from the sun. Kepler discovered some of the principal laws by which the motions of the planets are governed. He was the first that demonstrated, by calculations equally difficult and laborious, that *they must revolve in elliptical, and not in circular orbits.* He calculated by the observations of Tycho, the distance of Mars from the Sun in different parts of his orbit, and proved that it could not possibly be adjusted to the circumference of a circle. Newton showed afterwards, by the theory of attraction, that the curve which a planet describes would be strictly an ellipsis, of which the central star (or sun) occupies one of the foci, were it not for the slight irregularities occasioned by the attractions of the other planets. Let A E P G (Pl. XXVI. fig. 112.) be an ellipsis, or the course of a planet. The central star or sun is at S, which is one of the foci.

The second law of Kepler is, that *the squares of the times of the revolutions of the planets are as the cubes of their mean distances from the sun.* That is, if we compare the square of the time which any two of the primary planets occupy in completing their orbits, we shall find between these two squares the same proportion as between the cubes of the mean distances S E of these two planets from the sun. Thus, if we know the times of the revolution of two planets, we can thence compute what are their respective distances from the sun; and if we are made acquainted with the true distance of the one, we shall easily find the true distance of the other, as indeed the distances of all of which we know the time of their periodical revolutions.

Thus, if we suppose the planet Venus to revolve round the Sun in 224 days, and the Earth in 365; and if we admit the mean distance of the earth from the sun to be 95 millions of miles—then, as the square of 365 is to the square of 224, so will be the cube of 95,000,000 to a fourth number, which will show the cube of Venus's mean distance from the sun; and if the cube-root of this number is found, it will give about 68 millions of miles for the mean distance of Venus from the Sun.

The third law of Kepler is, that *the areas are in proportion to the times:*—That is, that the time occupied by a planet in passing the different arcs AD, DE of its orbit are to one another, as the areas of the trilineal spaces A S D, D S E terminated by these areas, and by the right lines AS, DS, and DS and ES; these areas are, by the same reasoning, to one another, as the time which the planet employs in passing through the arcs which terminate them. Hence we see that these times are shorter in proportion as the planet is nearer the sun, for then the area of the triangle is so much smaller. Newton has proved that these three laws are necessary consequences of the projectile force combined with the centripetal or attractive force, which retains the planets in their orbits; and the demonstration, now much simplified, finds a place in all our higher treatises of mechanics and astronomy.

Astronomers have divided the planets into two classes; the first class they call *primary planets, principals.* They are eleven in number, viz. Mercury, Venus, the Earth, Mars, Ceres, Pallas, Juno, Vesta, Jupiter, Saturn, and the Georgium Sidus or Uranus. Those of the second class they call *secondary planets* or otherwise *satellites* or *moons.*

The *primary* planets are such as revolve round the sun *only.* These are also divided into *superior* and *inferior*; those being called superior planets whose distance from the sun is greater than that of the earth, and those inferior planets whose distance is less than that of the earth.

The superior planets are, Mars, Ceres, Pallas, Juno, Vesta, Jupiter, Saturn, and Uranus, which are further from the sun than the earth is, and which, consequently, environ the latter in their revolution: it is for this reason we see them sometimes on one side of the sun, and sometimes on the other. The inferior planets are, Mercury and Venus, which are nearer the sun than the earth, and which, consequently, never environ the latter in their revolution. On this account we see them always on the same side as the sun, and never in opposition, because this earth is never between them and the sun.

It has been already stated that the apparent diameter of the sun, viewed at his mean distance from the earth, is $32' \, 3''{\cdot}3$. The apparent diameters of the planets seen from the earth bear a relation to their real size, and the distance of each. But, in comparing these diameters with one another, or with that of the sun, they are supposed to be seen all at a distance equal to the mean distance of the earth from the sun, as in the following table.

A TABLE of the mean apparent diameters of the sun, and of the primary planets, seen from the earth; and of the comparison of these diameters with that of the sun.

The Names of the Planets.	Apparent Diameters. Min.	″	‴	Diameters of the Planets compared with that of the Sun.
The Sun -	32	3	18	One
Mercury	0	7	0	1-274th
Venus -	0	27	0	1-116th
The Earth -	0	0	0	1-113th
Mars -	—	—	—	1-168th
Ceres -	0	1	0	——
Pallas -	0	0	5	——
Juno -	0	3	0	——
Vesta -	0	0	5	——
Jupiter -	0	38	12	1-10th
Saturn -	0	18	0	1-11th
His ring -	0	37	0	1-5th
Uranus -	0	3	12	1-25th

When once the apparent diameters of the planets are known, seen all at the same distance, it is easy to determine the size of each planet in terrestrial diameters. And as the real diameter of the earth is known in leagues, we may thence calculate the number of leagues which the real diameter of each planet contains. This may be seen by the following Table, in which the terrestrial diameter is taken for unity.

TABLE of the diameters of the sun and the primary planets in terrestrial diameters, and in leagues of 2283 French fathoms each.

Names of the Planets.	Size of the Planets. In Terrestrial Diameters.	In Leagues.	English Miles.
The Sun -	112 27-34ths	323,155	813,246
Mercury -	0 7-17ths	1180	3,224
Venus -	0 33-34ths	2784	7,867
The Earth -	1	2865	
Mars -	0 2-3ds	1921	4,139
Ceres -	- - -	- - - -	160
Pallas -	- - -	- - - -	80
Juno -	——	——	——
Vesta -	——	——	——
Jupiter -	11 2-5ths	32644	89,170
Saturn -	10 1-10th	28939 1-half	79,042
His ring -	23 1 half	67512	
Uranus -	4 1-half	12892	85,112

The magnitude of the planets compared with one another, are as the cubes of their diameters. We have seen in the preceding table the size of their diameters compared with that of the earth; by cubing them, therefore, we shall have the size of the planets themselves, compared with that of the earth, which is regarded as unity.

TABLE of the magnitude of the sun and primary planets compared with that of the earth.

Names of the Planets.		Magnitude. Almost.	In Decimals.
The Sun	-	1435023	1435022,666239
Mercury	-	0 3-43ds	0,078372
Venus	-	0 10-11ths	0,917559
The Earth	-	1	1,000000
Mars	-	0 1-10th	0,301445
Ceres	-	———	———
Pallas	-	———	———
Juno	-	———	———
Vesta	-	———	———
Jupiter	-	1479 1-4th	1479,231780
Saturn	-	1030	1030,173430
Uranus	-	91 1-4th	91,250000

The density of the planets is calculated in the same manner as that of the sun; by the quantity of their action one upon another. They are found to be such as are expressed in the following Table, and are compared with the density of the earth taken for unity.

TABLE of the densities of the sun and of the primary planets, compared with that of the earth.

Names of the Planets.		Densities. Almost.	In Decimals.
The Sun	-	0 1-4th	0,254630
Mercury	-	2 2-53ds	2,037700
Venus	-	1 11-40ths	1,275000
The Earth	-	1	1,000000
Mars	-	0 3-4ths	0,729170
Ceres	-	———	———
Pallas	-	———	———
Juno	-	———	———
Vesta	-	———	———
Jupiter	-	0 1-9th	0,229840
Saturn	-	0 2-19ths	0,104500
Uranus	-	0 2-9ths	0,220401

Since the magnitude of the planets, and also their densities, are known relative to the earth, it is easy to know their solidity, by multiplying these two quantities the one by the other, relative to that of the earth, which is taken for unity.

TABLE of the solidity of the sun and of the primary planets compared with that of the earth.

Names of the Planets.	Solidity. Almost.	In Decimals.
The Sun -	365400	365399,821504
Mercury -	0 15-94ths	0,159699
Venus -	1 1-6th	1,169388
The Earth -	1	1,000000
Mars -	0 2-9ths	0,219805
Ceres -	———	———
Pallas -	———	———
Juno -	———	———
Vesta -	———	———
Jupiter -	340	339,986632
Saturn -	108	107,653123
Uranus -	17 3-4ths	17,740612

The proper motion of each of the primary planets is from west to east in an elliptical orbit, (Pl. XXVI. fig. 112.) AEPG, the sun forming one of the foci. The plane of the orbit of the earth is called the ecliptic, as I have before explained. The orbits of all the other planets are differently inclined to it, but there is not any of the old planets which departs more than eight degrees from the ecliptic; so that they are all contained within the zodiac. It is this departure from the ecliptic, which is called the *latitude* of the planets, in like manner as the *latitude* of the stars denotes their distance from the ecliptic.

TABLE of the inclination of the orbits of the primary planets from the plane of the ecliptic.

Names of the Planets.		Inclination. Deg.	Min.	″
Mercury	-	7	0	9
Venus	-	3	23	32
The Earth	-	0	0	0
Mars	-	1	51	3
Ceres	-	10	37	34
Pallas	-	34	50	40
Juno	-	21	0	0
Vesta	-	7	8	46
Jupiter	-	1	18	52
Saturn	-	2	29	38
Uranus	-	0	46	26

These orbits differ greatly in extent in proportion as the planets are respectively more or less distant from the central star of the system, the sun. The means by which these distances are ascertained have been mentioned before, when we spoke of the second law of Kepler. But it must be evident that we must know the distance of some one planet from the sun, before we can compute the distance of any other by comparing the time of its orbit with that, the distance of which from the sun is known.

As we exist upon the earth, our calculations must originate from the planet we inhabit. Here only we have certain grounds, and, whatever we measure of the arch of the heavens must have something relative here to serve as the basis of our operation. The *horizontal parallax*, as it is called, has therefore been a common basis employed for measuring the distances of the heavenly bodies from the earth. With respect to the moon, this method answers with great accuracy, but with respect to the sun it is liable to great error, for reasons which I shall afterwards state, and as to the fixed stars, it is altogether inapplicable. Indeed, from their great distance they can have no parallax of this kind.

To explain what I have now remarked, I must refer to the diagram (Pl. XXVI. fig. 113.) where B A G represents one half of the earth, A C its semidiameter, S the sun, supposed at an immense distance, *m* the moon, and E K O L a part of the moon's orbit. C R S is a line representing the rational horizon of an observer at A extended to the sun; H A O his sensible horizon extended to the moon's orbit. A L C is the angle under which the earth's semi-diameter A C is seen from the moon at L. A S C is the angle under which it is seen from the sun at S. Now it is evident that the angle A L C is equal to the angle O A L, and the angle A S C to the angle O A *f*; and consequently, as the angle O A *f* is much less than O A L, the earth's semidiameter appears much greater as seen from the moon at L than from the sun at S, and therefore the earth is at a much greater distance from the sun than from the moon.

If then we can measure either of the angles A L C or O A L, which are in effect the same, we shall have the moon's distance from the earth.

To effect this operation, take a graduated instrument DAE, having a moveable index with sight-holes, and let it be fixed so that its plane surface may be parallel to the plane of the equator, and its edge AD in the plane of the meridian. So that when the moon is in the equinoctial, and on the meridian A D E, she may be seen through the sight-holes, when the edge of the moveable index cuts the beginning of the divisions at O on the graduated limb D *e*, and let the precise time when she is thus seen be carefully noted. Again, when the moon has reached the sensible horizon at O, let her be viewed in the same manner through the sight-holes, and the time be precisely noted, making proper allowance for the refraction. Then, as the moon makes her apparent revolution from the meridian to the meridian again on an average in 24 hours and 43 minutes, deduct the time in which she passes from E to O, from 6 hours 12 minutes, and then you will have the time in which she describes the arc OL, and this will enable us to measure the moon's horizontal parallax, or angle O A L. For as the time of the moon's describing the arc E O is to 90 degrees, so is 6 hours 12 minutes to the degrees of the arc D *d e*, which measures the angle E A L, from which subtract 90 degrees, and there remains the angle O A L, equal to the angle A L C, under which the earth's semidiameter AC is seen from the moon.

Now, since the sum of the angles of a plane triangle makes two right angles, or 180 degrees, and the sides of a triangle are always proportioned to the sines of the opposite angles, say, as the sine of the angle A L C at the moon L is to its opposite side A C, the earth's semidiameter, or 3985 miles, so is radius the sine of 90 degrees, or of the right angle A C L to its opposite side, which is the moon's distance at L from the observer's place at A—Or, so is the sine of the angle C A L to its opposite side C L, which is the moon's distance from the earth's centre, and which will prove to be about 240,000 miles. The angle C A L is equal to what the angle O A L wants of 90 degrees.

The sun's distance cannot so easily be determined, since his horizontal parallax, or the angle O A S, equal to the angle A S C, is so small as to be scarcely perceptible, being not more than 8 seconds and a half, whereas the moon's horizontal parallax, or the angle O A L, is very discernible, being at a mean 57′ 18″, which is more than 400 times greater than that of the sun.

The sun's horizontal parallax, therefore, for these reasons, could not be ascertained with any degree of accuracy till the transits of Venus over the sun's disc, which happened in the years 1761 and 1767, for at such an immense distance, and in so small an angle, the error of one second will create an error of seven millions of miles. Hence the amazing difference in the calculations of different astronomers. Ptolemy and his followers, as well as Tycho Brahe and Copernicus, conceived the sun's distance to be 1200 semidiameters of the earth; Kepler nearly 3500, and Ricciolus doubles that distance.

The celebrated Dr. Halley first pointed out the means of solving this difficult problem, which he terms "the most noble in the sciences," upon theoretical principles, though in the course of nature he could never expect to see them reduced to practice.

Venus passes the sun, or is, in the astronomer's phrase, in conjunction with it, very often; and if the plane of her orbit were coincident with the plane of the ecliptic, she would on such occasions appear like a spot on the sun for about seven hours. But the orbit of Venus only intersects the ecliptic in two points, which are called its nodes. Venus, therefore, can never be seen on the sun but at those inferior conjunctions which happen in or near the nodes of her orbit; and though this circumstance seldom happens, the time of its occurring is easily calculated by astronomers. The last transit before the time of Dr. Halley was in the year 1639, and he calculated that one would again occur in 1761, and another in 1769.

Though the sun's distance, therefore, is so great that the earth's diameter is only a point in comparison, and his parallax, for the reasons already assigned, could not be determined with accuracy, the case is very different when Venus is perceptibly between the earth and the sun, for her distance is between three and four times less than that of the sun. If, therefore, when Venus in her transit enters upon the sun's disc, she is observed by two different spectators on different parts of the earth's surface, she will appear to each of them at the same instant on different parts of the sun. Dr. Halley, therefore, recommended that some scientific men should be sent to different parts of the world, where the transit could be observed with accuracy; that the precise times of her entrance and egress from the face of the sun should be carefully noted by each; and from these observations, compared with the time which she would occupy in passing over the sun's surface, as seen (by supposition) from the earth's centre, he demonstrated that not only the parallax of Venus but that of the sun might be found.

I shall not trouble you with the detail of this problem. It is founded on the principles already explained in treating of the moon's horizontal parallax, and is explained at large in different treatises on Astronomy*. Let it suffice

* To those who wish to enter more deeply into the sub-

to say, that the transits in 1761 and 1769 were carefully observed by very eminent astronomers

ject, the following extract from Mr. Nicholson's Astronomy will be satisfactory.

"The planet Venus passes the sun twice in revolving from any position of elongation to the same position again. At those times this planet is said to be in conjunction with the sun.

"When the planet Venus is situated in a line between the sun and the earth, it is said to be in its inferior conjunction; and when it is in the opposite part of its orbit, the sun being in a line between it and the earth, it is said to be in its superior conjunction. If the orbits of the earth and Venus were in the same plane, it is evident that Venus would pass behind the sun with a direct motion every superior conjunction, and would pass over its disc, or before it, with a retrograde motion every inferior conjunction. But as Venus's orbit is inclined to the ecliptic in an angle of about $3\frac{1}{2}$ degrees, this planet will, in general, pass to the northward or southward of the sun, and will only be visible on its disc when the inferior conjunction happens at or near one of the nodes. This happens but once (or sometimes twice at an interval of about 8 years) in more than 120 years.

"To show how this transit is applied to the purpose of finding the sun's distance, we shall pass over those elements that enter into the computation previous or subsequent to actual observation, and shall only explain the general principles on which the method is founded.

"Let *s* (Pl. XXVIII. fig. 117.) represent the Sun, E the earth, V, U, W, the planet Venus in different positions, the arc L N a part of the earth's orbit, and the arc O M a part of the orbit of Venus. Then, because the angular velocities of Venus and the earth are known, as also their proportional distances, it will be easy to compute the time Venus will employ in passing through the arc in different parts of the world, and the sun's horizontal parallax was determined to be about

V W, which when viewed from the earth, is equal to the known chord of the sun C D; the heliocentric value or length of the arc V W may likewise be readily found. Suppose then an observer at A on the earth's surface to view the planet Venus at V, it will appear just entered within the sun's disc at C, and passing in the arc V W, will appear to describe the line C D, arriving at D at the end of the computed time. But during this time the observer will, by the earth's diurnal revolution, be carried from A towards P; and arriving at P at the same instant that Venus arrives at U, will behold the transit just finishing at D: consequently it will be of a duration proportionally as much shorter than the computed time, as the heliocentric arc V U is shorter than V W. The arc V W is known by computation, therefore, since Venus's motion may in very small arcs be reckoned uniform,

> "As the computed time
> Is to the computed arc V W,
> So is the observed time
> To the arc V U;

which being taken from V W, leaves the arc U W, that subtends the angle U D V. This last angle is the parallax of the base A P; and the base A P is found by the analogy

> "As one day or 24 hours
> Is to the circumference of the earth (or parallel of latitude)
> So is the observed time
> To the arc A P, whose chord is the base.

"But because the minutest errors in a business of this nature are of very great consequence, and because the length of the arc V W, depending on the sun's diameter, can scarcely be obtained by calculation to that extreme degree of exactness, which is requisite, it is advisable to take another observation on a place so situated on the earth, that, 8 seconds, as already intimated, and his distance from the earth to be about ninety-five millions of miles.

The distance of the sun from the earth being well ascertained, the distance of the other planets may be easily calculated by the second law of Kepler; as their orbits or rather the time occupied in traversing their orbits, is known by observation. The following table will be found, believe, to exhibit a fair statement of their respective distances.

the observer being carried in a direction apparently contrary to the former, the errors may counteract each other.

"Let the representations be as in the last figure. If the sun has declination at the time of the transit, B (fig. 118.) will represent the pole towards which the sun declines. The observer at A, if at rest, would behold the transit during the time Venus passes from V to W; but being by the earth's diurnal revolution carried from A through the arc A E P to P, and arriving at P at the instant in which Venus arrives at U, he will perceive the transit just finishing at D; consequently its duration will be as much longer than the computed time as the heliocentric arc V U is longer than V W. V U being found by the before-mentioned analogy, the difference between V U and V W is W U or the parallax of A P, as before.

"Now, in these two cases, a similar error will have a contrary effect in the first to that which it has in the latter. For, if, by any error, the computed arc V W (fig. 117.) be taken too large, the arc U W, and consequently the parallax, will come out too great. But in the latter observation, if the computed arc V W (fig. 118.) is taken too large, the arc W U, and consequently the parallax will come out too little. Therefore the mean between two such observations will be much more to be depended on than either singly.

TABLE of the mean distances of the primary planets from the sun, in French leagues of 2283 fathoms each, and in English miles in round numbers.

Names of the Planets.	Mean Distances. In Leagues.	Mean Distances. In English Miles in round numb.
Mercury -	13,156,246	37,000,000
Venus -	25,144,166	68,000,000
The Earth -	34,761,680	95,000,000
Mars -	52,966,024	144,000,000
Ceres -	86,904,200	260,000,000
Pallas -	———	266,000,000
Juno -	———	253,000,000
Vesta -	———	225,000,000
Jupiter -	180,794,802	490,000,000
Saturn -	331,628,860	900,000,000
Uranus -	663,315,425	1800,000,000

The revolutions of the planets may be considered as relative to the sun, or as relative to the earth. In the first case they are called *periodical revolutions;* that is, the time which the planets employ in revolving about the sun in coming again to a fixed point in the heavens. In the second, they are called *synodical revolutions;* that is, the time which the planets seen from the earth employ in returning to the sun; or the time which passes between the mean conjunction and the next following. This time is very different from that of periodical revolutions, as may be seen in the following table.

TABLE of the duration of the synodical revolution of the primary planets, compared with that of their periodical revolutions.

Names of the Planets.	Duration of the Synodical Revolutions.	Duration of the Periodical Revolutions.
Mercury -	About 116 Days	About 88 Days.
Venus -	1 Year 219 ——	224 ——
Mars -	2 —— 59 ——	1 Year 321 ——
Ceres -	- - - - - -	About 1681 ——
Juno -	- - - - - -	—— 1591 ——
Pallas -	Unknown Period.	—— 1682 ——
Vesta -	- - - - - -	—— 1335 ——
Jupiter -	1 Year 34 Days.	11 Years 313 ——
Saturn -	1 —— 13 ——	29 —— 154 ——
Uranus -	1 —— 5 ——	83 —— 130 ——

The two inferior planets, Mercury and Venus, as well as three of the superior, Mars, Jupiter, and Saturn, were known to the early astronomers. The Georgium Sidus, or Uranus, was discovered in the year 1781, by Dr. Herschell; Ceres was discovered the first day of the present century, by Mr. Piazzi, an Italian astronomer; Pallas, by Dr. Olbers of Bremen, in 1802; Juno, by Mr. Harding, at Lilienthal, in 1804; and Vesta, by Dr. Olbers, in the spring of the year 1807.

The general character and appearance of the principal planets will be best understood by a reference to Plate XXVII. and therefore few observations will be necessary on this subject.

MERCURY, from his nearness to the sun, is but seldom visible. No spots have as yet been discovered on his surface, and therefore his rotation on his axis is not known. Mercury and Venus, being inferior planets, can never appear quite at the full to us, but must show phases analogous to those of the moon, according to their relative positions as to the sun and the earth.

Venus is the most brilliant in appearance of all the planets; and she is called the morning or evening star, according as she precedes or follows the sun; in the first case she appears to the right, in the second to the left of that luminary. Some spots have been discovered on her surface, yet her rotation on her axis has not been positively ascertained. She is said to be surrounded by an atmosphere of about fifty miles in height.

Mars, the first of the superior planets, is distinguishable from the rest by the red appearance of his disc, which all agree in attributing to the density of his atmosphere. His figure is an oblate spheroid, like that of the earth, which indeed he resembles most in all circumstances. Spots have been observed on his surface, from which his diurnal rotation has been ascertained, as well as the inclination of his axis to the ecliptic, which is 59° 42′. Two large white circular spots are observed at his poles, whence it is conjectured that they are continually covered with snow.

Ceres, Pallas, Juno, and Vesta, are too

small, the diameter of none of them probably exceeding 100 miles, to admit of any accurate observations by the best instruments now in use.

Jupiter is by far the largest planet in our system, and the brightest next to Venus in appearance. When viewed through a good telescope, several belts, or bands, darker than the general surface (see Pl. XXVII. figs. 115 and 116.) are observed across his disc parallel to his equator, which, as they are constantly varying, are supposed to be a series of clouds in his atmosphere. Spots have also been seen on his disc between the belts; and from their disappearance and reappearance, his diurnal rotation on his axis has been computed at about 9 hours 55 minutes. His axis is nearly perpendicular to his orbit; his figure is an oblate spheroid, much flattened at the poles.

Saturn, when viewed through a good telescope, is the most extraordinary and interesting of all the planets. He is surrounded by a flat, circular, broad, and luminous ring, (see fig. 114.) which does not touch the planet, but casts a shadow upon it, and is itself divided into two parts. With respect to the nature of this extraordinary phænomenon, no probable conjecture has yet been formed.

The Georgium Sidus, or Uranus, is too far distant to admit of such accurate observation as could be wished. It may sometimes be seen as a star by the naked eye; but its moons, or satellites, can only be seen by a good telescope.

Besides these, there are other bodies attached to our system, which, although their orbits are singularly eccentric, have yet many things in common with those which we have been describing; they are called COMETS.

They are not luminous of themselves, but, like the planets, are opake bodies, shining only by the light of the sun, which they reflect towards us. All the comets revolve round the sun in a manner peculiar to themselves, that is, in elliptical orbits exceedingly long and eccentric, yet regulated by laws similar to those of the planets themselves, each describing equal areas in equal times, about the sun as a centre of force. On this principle astronomers have attempted to calculate the period of their return, and in one case at least with success, since it is generally agreed that the comet which appeared in 1759 is the same which was observed in 1531, 1607, and 1682. Its periodical revolution is therefore completed in about 76 years, and it may be consequently expected again in the year 1835.

Some of the comets move from West to East, like the planets, while others proceed in a contrary direction from East to West, and in the contrary order of the signs of the zodiac. Some pass nearly in the line of the ecliptic, and some almost perpendicular to it. These orbits being extremely protracted and eccentrical, the aphelion of a comet is consequently at an immense distance from the sun. In that case the light which they receive from him is too feeble to be reflected to us, and they are only visible when they approach their perihelion. The time of their appearance is, therefore, very short, compared with the time of their disappearance. In order to describe the course of a comet, let ABPC (Pl. XXIX. fig. 120.) be the very long orbit of a comet, in one of whose foci S is placed as the sun; the aphelion in A; the perihelion in P. The comet is not visible to us but when it approaches towards B, and during the time which it passes the arc BPC of its orbit. But the time is considerably shorter than that which it employs to pass the other portion of its orbit CAB, for these two reasons: first, because the arc BPC is much shorter than the arc CAB; and in the second place, because the comets, like the planets, are slower in their course while they depart further from the sun; and, on the contrary, they are swifter as they approach the sun. It requires much less time to pass over the portion BPC of their orbit which is visible to us, than the other portion CAB.

The most luminous part of the comet is commonly surrounded with a kind of atmosphere, which again seems to emit from it a fainter light, somewhat resembling the Aurora Borealis. The interior part is called the nucleus, and the exterior the beams, or *hair*, in Latin *coma*, whence the name comet, or hairy star.

It happens commonly, that a comet is accompanied by a train of light, sometimes very long, as at L, and always directed to that part of the heavens which is directly, or nearly, opposite to the sun; this is called the *tail* of the comet. Newton attributes the rise and the direction of the tails of comets to the levity of certain particles, which the sun raises, by its heat, from the atmosphere of the comet, when it approaches its perihelion. He compares it to the smoke from a burning body, which rises perpendicularly if the body is at rest, or obliquely if the body is in motion. In fact, the tails of comets, which always rise from the side which is opposed to the sun, have a degree of curvature which is turned from the side towards which the course of the comet is directed. M. de Mairan attributes the formation of the tails of comets to a part of the solar atmosphere, with which he supposes the comets to be charged, and which they draw along with them in approaching their perihelion. Other philosophers have supposed the tails of comets to be collections of electric fluid, rendered at once luminous and stationary. But all this is mere conjecture.

The number of the comets is certainly very considerable. Riccioli enumerates 154, others assert that 450 had been seen previous to the year 1771. The tables of Berlin estimate them at 700; and some have even supposed that there are millions. They differ greatly in size: some are so small as to appear like the fixed stars, others not larger than Venus; while Hevelius observed one in 1651, which was equal in apparent magnitude to the full moon; its light was, however, much more pale and dim, and its aspect, on the whole, dismal. The nucleus of the planet which appeared in the year 1807 was very large; while the comet of 1811 had scarcely any perceptible solid nucleus. The beautiful comet of the summer of 1819 had a very evident nucleus: its tail, also, was for a few evenings very splendid.

LECTURE XX.

ASTRONOMY.

THE SECONDARY PLANETS.

THE Secondary Planets are those which perform their revolution round other planets, which themselves make their revolutions round the sun. They are reckoned eighteen in number, viz. the moon, the four satellites of Jupiter, the seven satellites of Saturn, and the six satellites of Uranus.

I shall first speak of the moon; since, from her proximity to the earth, we have a better opportunity of observing her motions and phænomena, than we have of the other secondary planets.

The apparent diameter of the moon, if seen at the same distance from the earth as the sun, would be little more than four seconds. Whence we may conclude that her diameter is at least 390 times less than that of the sun. The moon's diameter is about $\frac{11}{40}$ths that of the earth, or about 2170 miles. The whole bulk of the moon is about $\frac{1}{41}$ of that of the Earth.

The moon being much nearer to the earth than the planets are, and having an apparent diameter of more than half a degree, has been known ever since the creation; whereas the satellites of the other planets have only been known to astronomers since the invention of telescopes.

The moon completes her revolution in somewhat less than a month, during which period she is once in conjunction with the sun, and once in opposition. While the earth traverses not quite a twelfth part of her orbit, that is, not the whole of one of the signs of the zodiac, the moon completes her revolution or orbit round the earth.

Since the moon has no other light than what she receives from the sun, it follows that she can never have more than one half of her surface enlightened; but it depends upon the relative position of the spectator with regard to the sun, whether more or less of the face of the moon will appear enlightened. For, being of a globular figure, it depends upon this position what part of her orb shall receive the rays of the sun in such a manner as to reflect them back to the eye of the spectator. These different appearances of the moon are called her phases*.

Thus, when the spectator is placed at T, between S, the sun, and moon, at L, (Pl. XXVIII. fig. 119.) the whole side of the moon which is opposed to him will be enlightened, and she is

* These appearances will be pretty correctly represented by moving an ivory ball suspended from a string round the flame of a candle, and observing in what manner the light is reflected from different parts of its surface, according to the position in which it is held.

then said to be at the *full.* In proportion as she approaches the sun, only a part of her surface will be enlightened, as at P, when not more than half will be in that state. She is then said to be in her *last quarter.* In fine, the enlightened parts become less and less to a spectator on the earth as she advances towards the sun, till at last she comes between the sun and the earth at N, when she is altogether invisible, and this last phasis is called the *new moon.* She has not long passed this point before she begins to present a small portion of her surface enlightened. When she is at Q, she is said to be in her first quarter, and the enlightened part continues augmenting till she is again at the full.

When the moon is placed between the four parts A, B, C, D, and at an equal distance from each point, she is said to be in her *octants.* In the first A, and in the fourth, D, she presents only one-eighth of her surface enlightened, and in the second, B, and the third, C, three-eighths of her surface are enlightened.

In the phases A, Q, B, which are between the new and full moon, the convexity of the enlightened part is turned towards the west, and in those of C, P, D, which are between the full and the new moon, this convexity is directed towards the east. All these changes, or *phases,* will be rendered more evident to the student, if he will in every position of the moon, imagine tangents to the moon's orbit, drawn through her centre, and observe what portion of the illuminated portion of the moon comes below that tangent, with regard to the earth.

About the first octant and the fourth, the enlightened portion of the moon is in the form of a crescent. The rest of the body of the moon is then seen pretty distinctly. This results from the light which is reflected upon the moon from the surface of the earth.—For, as we have the light of the moon, so the moon has the light of the earth. In other words, the earth is a moon to the moon, and with similar phases.

The revolution of the moon round the earth measured by any fixed point in the heavens is 27 days 7 hours 43 minutes and 11 seconds. This is called a periodical month. But the time which intervenes from one conjunction with the sun to another is 29 days 12 hours 44 minutes and 3 seconds, and this is called a synodical month or lunation. The reason of this difference is that, during the synodical revolution of the moon, the earth advances on an average about 27 degrees on the ecliptic.

To render this sufficiently intelligible we must have recourse to a diagram. In fig. 123. (Pl. XXIX.) let S represent the sun, FC a part of the earth's orbit, or ecliptic, M D a diameter of the moon's orbit when the earth is at A, and *m d* the same diameter when the earth is at B. While the earth is at A, if the moon is at D, she will be in conjunction, and if the earth were to continue at A when the moon had completed its orbit from D, through M, and to D again, it would be exactly in conjunction, and the periodical and synodical month would be the same. But as the earth does not continue at A, but moves to B, and as the moon's orbit moves with it, the diameter of that orbit will then be in the position *m d*, and the moon will be at *d*. If then the moon is at *d*, while the sun is at S, it will be seen by the figure, that it cannot be in conjunction, but must move to *e*, in the diameter *f e*, and consequently describe the arc *d e* to bring it in conjunction with the sun. To do this occupies at a mean about 2 days 5 hours and 51 seconds; and the synodical is just so much longer than the periodical month.

It is almost unnecessary to mention to you that the diurnal rotation of the earth about its axis occasions an apparent daily revolution of the moon from east to west, or, in common language, the *rising* and *setting* of that luminary. But, during this apparent revolution of the moon from east to west, she in reality advances in her orbit about 13 degrees from west to east. There is therefore an apparent daily retardation in the course of the moon, as she rises and sets each day about 49 minutes later than the preceding. This, however, is strictly true only as to the equatorial regions, and under circumstances to be afterwards explained. The moon turns round on her own axis in the same time that she makes her periodical revolution round the earth *. On this account she always presents to our view the same part of her surface, or nearly the same face. There may, however, be observed a little variation in the situation of her spots, or in the position of her face in general, as presented to the spectator. This is called a *libration*, and depends on the different aspects which the moon assumes in consequence of the diurnal motion of the earth on its axis, and of the inclination of the axis of the moon in describing her elliptical orbit.

In the course of a year the moon makes 13 and ½ revolutions upon her axis; and as in each of these revolutions the sun enlightens successively every part of her surface, it follows that the inhabitants of the moon, if there be any, would enjoy about 13 days and a third.

The phænomenon of the harvest moon is not generally understood. I shall endeavour to explain it, following chiefly Mr. Ferguson, and deviating but little from the simple language of that justly popular philosopher.

It has already been stated that the moon rises about 49 minutes later every day than on the preceding; but this is strictly true only with regard to places on the equator. In places of considerable latitude there is a remarkable dif-

* The inhabitants of the moon, therefore, if we suppose there are any, would have but one day and one night in the course of a month.

ference, especially in the time of harvest, with which farmers were better acquainted than astronomers till of late; and they gratefully acknowledged the goodness of God, in giving them an immediate supply of moonlight after the setting of the sun, for their greater conveniency in reaping the fruits of the earth, without understanding the means by which this was effected. About the equator, where there is no variety of seasons, and the weather changes seldom, and at stated times, moonlight is not necessary for gathering in the produce of the earth. At the polar circles, where the mild season is of very short duration, the autumnal full moon rises at sunset from the first to the third quarter. And at the poles, where the sun is for half a year absent, the winter full moons shine constantly without setting from the first to the third quarter.

It is easy to state in general terms that these phænomena are owing to the different angles made by the horizon and different parts of the moon's orbit; and that the moon can be full but once or twice in a year in those parts of her orbit which rise with the least angles. But to explain this subject intelligibly, I must dwell somewhat longer upon it. The plane of the equinoctial is perpendicular to the earth's axis; and therefore, as the earth turns round its axis, all parts of the equinoctial make equal angles with the horizon both at rising and setting; so that equal portions of it always rise or set at equal times. Consequently, if the moon's motion were equable, and in the equinoctial, at the rate of 12 deg. 11 min. from the sun every day, as it is in her orbit, she would rise and set about 49 minutes later every day than on the preceding; for 12 deg. 11 min. of the equinoctial, rise or set in about that time in all latitudes.

But the moon's motion is so nearly in the ecliptic, that we may consider her for the present as moving in it. Now the different parts of the ecliptic, on account of its obliquity to the earth's axis, make very different angles with the horizon as they set or rise. Those parts or signs which rise with the smallest angles set with the greatest, and the contrary. In equal times, whenever this angle is lost, a greater portion of the ecliptic rises than when the angle is larger; as may be seen by elevating the pole of a globe to any considerable latitude, and then turning it round its axis. Consequently, when the moon is in those signs which rise or set with the smallest angles, she rises or sets with the least difference of time; and with the greatest difference in those signs which rise or set with the greatest angles.

In northern latitudes, the smallest angle made by the ecliptic and the horizon is when Aries rises, at the time when Libra sets; the greatest when Libra rises at the time Aries sets. From the rising of Aries to the rising of Libra the angle increases; and from the rising of Libra to the rising of Aries it decreases in the same proportion. By this it appears that the ecliptic rises fastest about Aries, and slowest about Libra. On the parallel of London, as much of the ecliptic rises about Pisces and Aries in two hours as the Moon goes through in six days; and therefore, while the moon is in these signs, she varies but two hours in the time of her rising for six days together; that is, she rises about twenty minutes later every day or night than on the preceding, at a mean rate. But in fourteen days afterwards the Moon comes to Virgo and Libra, which are the opposite signs to Pisces and Aries; and then she differs almost four times as much in rising; namely, one hour and about fifteen minutes later every day or night than the former, while she is in these signs.

The ecliptic, together with the fixed stars, make $366\frac{1}{4}$ apparent diurnal revolutions about the earth in a year, the sun only $365\frac{1}{4}$. Therefore the stars gain three minutes fifty-six seconds upon the sun every day; so that a sidereal day contains only twenty-three hours fifty-six minutes of mean solar time; and a natural or solar day twenty-four hours. Hence twelve sidereal hours are one minute fifty-eight seconds shorter than twelve solar hours.

The sun advances almost a degree in the ecliptic in twenty-four hours, the same way that the moon moves; and therefore the moon by advancing 13 1-6th degrees in that time, goes little more than twelve degrees farther from the sun than she was on the day before. The moon goes round the ecliptic in twenty-seven days eight hours; but not from change to change in less than twenty-nine days twelve hours; so that she is in Pisces and Aries once in every lunation, and in some lunations she is twice in one of these signs.

As the moon can never be full but when she is opposite to the sun, and the sun is never in Virgo and Libra but in our autumnal months, it is plain that the moon is never full in the opposite signs, Pisces and Aries, but in the harvest and hunter's moon. And therefore we can have in a year only two full moons, which rise so near the time of sunset for a week together, as above mentioned.

Here it will probably be asked, why we never observe this remarkable rising of the moon but in harvest, since she is in Pisces and Aries twelve times in the year besides; and must then rise with as little difference of time as in harvest? The answer is plain; for in winter these signs rise at noon; and being then only a quarter of a circle distant from the sun, the moon in them is in her first quarter; but when the sun is above the horizon, the moon's rising is neither regarded nor perceived. In the spring these signs rise with the sun, because he is then in them; and as the moon changes in them at that time of the year, she is quite invisible. In summer they rise about midnight, and the sun being then three signs, or a quarter of a circle before them, the moon is in them about her third quarter; when rising so late, and giving but very little light, that rising passes unobserved. In autumn these signs, being opposite to the sun, rise when he sets, with the moon in opposition, or at the full, which renders her rising very conspicuous.

Hitherto, for the sake of being perfectly intelligible, I have supposed the moon to move in the ecliptic, from which the sun never deviates. But the orbit in which the moon really moves is different from the ecliptic; one half being elevated 5 1-3d degrees above it, and the other half as much depressed below it. The moon's orbit therefore intersects the ecliptic in two points diametrically opposite to each other; and these intersections are called the *moon's nodes.* So the moon can never be in the ecliptic but when she is in either of her nodes, which is at least twice between every two successive changes, and sometimes thrice. For, as the moon goes almost a whole sign more than round her orbit from change to change; if she passes by either node about the time of change, she will pass by the other in about fourteen days after, and come round to the former node two days again before the next change. That node from which the moon begins to ascend northward or above the ecliptic, in northern latitudes, is called the *ascending node*, and the other from which she begins to descend below the ecliptic southward, the *descending node.*

The moon's oblique motion, with respect to the ecliptic, causes some difference in the times of her rising and setting, from what, for the sake of perspicuity, I stated in the preceding paragraphs. When she is northward of the ecliptic, she rises sooner, and sets later, than if she moved in the ecliptic; and when she is to the southward of it, she rises later, and sets sooner. This difference is variable, even in the same signs, for the nodes recede about $19\frac{1}{2}$ degrees in the ecliptic every year. When the ascending node is in Aries, the southern half of the moon's orbit makes an angle of $5\frac{1}{3}$ degrees less with the horizon than the ecliptic does when Aries rises in northern latitudes. In fact, the angle is then only $9\frac{2}{3}$ degrees on the parallel of London. The moon consequently rises with less difference of time while in Pisces and Aries than if her track was exactly in the ecliptic. But in the course of 9 years and 112 days the descending node is in Aries, and then the moon's orbit makes an angle of $5\frac{1}{3}$ greater with the horizon when Aries rises, than the ecliptic does at that time, that is, about $20\frac{1}{3}$ degrees on the parallel of London; and this causes the moon to rise with greater difference of time in Pisces and Aries than if she moved in the ecliptic. The shifting of the nodes, however, scarcely ever affects the moon's rising so much, even in her quickest descending latitude, as not to allow us still the benefit of her rising nearer the time of sunset for a few days together about the full in harvest, than at any other time of the year.

The moon, when viewed through a telescope, presents a vast irregularity of surface. These inequalities are most apparent at the edge of her enlightened part, when she is not at or near the full; for the sun's rays are intercepted by the hills or prominences, so as to give that part of her surface a jagged appearance: and sometimes, to show the luminous tops of mountains, at a considerable distance from the illuminated disc. Upon mathematical principles, some of these prominences have been measured, and one of them is computed to be at least three miles in height.

Maps of the moon have been published, and her surface fancifully divided into lands and seas, and names were even assigned to both. The more correct discoveries, however, made with the powerful glasses of Dr. Herschell, have dissipated these pleasing illusions. Those parts which were formerly supposed to be seas are now found to be only cavities or valleys, which reflect the light less strongly than the more elevated parts. Through these instruments, in fact, the moon appears a mere volcanic mass, without water or atmosphere. That the moon has no atmosphere has by many been thought proved; for, say they, if she had, the edge of her disc would never appear so clear or well defined as it does; and when any of the fixed stars disappear behind the moon, they retain their full lustre till they touch her very edge, and then vanish in a moment. These circumstances, they affirm, could not take place if the moon had an atmosphere; for she would then have always round her a kind of mist or haze, and the stars would appear fainter when seen through it. Still, it must be acknowledged, that these reasons, though feasible, are by no means decisive.

This account of the moon may serve to give a general idea of a satellite, or secondary planet, particularly as to its orbit and phases; but whether or not, the satellites of the other planets exactly resemble our moon in the other circumstances which have been just mentioned, their immense distance will not allow us to determine.

The four satellites or moons of Jupiter were discovered by Galileo in the year 1610. The sixth and largest satellite of Saturn was discovered by Huyghens in the year 1655; three others by Cassini; the third in 1671; the fifth in 1672; the fourth in 1684; and the first and second, by Dr. Herschell, in 1789. The six satellites of Uranus or the Georgium Sidus were discovered by Dr. Herschell, who discovered the planet. Astronomers denominate the satellites with relation to their distances from the principal planet; they therefore call that the first satellite which is nearest the planet, the second satellite that which is nearest to the former, &c.

From the continual changes of their phases or appearances, it is evident that these secondary planets are also opaque bodies like the planets themselves, and shine only by means of the borrowed light which they receive from the sun.

The angles under which the orbits of Jupiter's moons are seen from the earth, at their mean distance from Jupiter, are as follow: the first 3′ 35″; the second 6′ 14″; the third 9′ 58″; and the fourth 17′ 30″. And their distances from Jupiter, measured by his semi-diameter, are thus: the first 5 2-3ds; the second 9; the third 14 23-60ths; and the fourth 25 18-60ths. This planet, seen from its nearest moon, would appear a thousand times as large as our moon does to us; waxing and waning in all its monthly shapes every 42½ hours.

Jupiter's three nearest moons fall into his shadow, and are eclipsed in every revolution; but the orbit of the fourth moon is so much inclined, that it passes by its opposition to Jupiter, without falling into his shadow, two years in every six. By these eclipses astronomers have not only discovered that the sun's light takes up eight minutes of time in coming to us; but they have determined the longitudes of places on this earth with considerable certainty, and with much greater facility, than by any other method yet known.

TABLE of the mean distances of the secondary planets from their principal planets.

Names of the Planets.		Mean Distances.	In French leagues.
	In Radii of the Earth.		
The Moon	59	—	84515
	In Radii of Jupiter.		
1st Satellite of Jupiter	5, 67	—	92540
2d - -	9	—	146898
3d - -	14, 38	—	234710
4th - -	25, 30	—	412946
	In Radii of Saturn.	Of the Ring	
1st Satellite of Saturn	4, 70	1, 93	65149
2d - -	5, 12	1, 47	83377
3d - -	7, 16	3, 45	116158
4th - -	18, 00	8, 00	270048
5th - -	52, 50	23, 23	884152
6th			
7th			
	In Radii of Uranus.		
1st Satellite of Uranus	16, 50	—	106165½
2d - -	19, 61	—	126401⅓
3d			
4th			
5th			
6th			

The secondary planets, like the primary, finish their revolutions in longer times, in proportion as they are further from the centre of their orbits, the relation of the square of the times, and the cubes of the mean distances obtaining equally with all, as may be seen by the following table.

TABLE of the duration of the periodical revolutions of the secondary planets round the principal planet.

Names of the Planets.	Duration of the Revolutions. days	hrs.	′	″	‴	In Seconds.
The Moon by affinity with the Stars.	27	7	43	11	36 or	2360591
—— by affinity with the Equinox.	27	7	43	5		2360585
1st Satellite of Jupiter	1	18	27	33		152853
2d - - -	3	13	13	42		306822
3d - - -	7	3	42	33		618153
4th - - -	16	16	32	8		1441923
1st Satellite of Saturn	1	21	18	27		163107
2d - - -	2	17	44	22		236662
3d - - -	4	12	25	12		390312
4th - - -	15	22	34	38		1377278
5th - - -	79	7	47	0		6853620
6th						
7th						

LECTURE XXI.

ASTRONOMY.

THE EARTH.

The earth is nearly of a spherical figure. The truth of this without having recourse to scientific principles, will appear sufficiently evident from the voyages of celebrated navigators such as 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 exact place whence they departed: which could never have happened had the earth been of any other form than spherical.

This form is also apparent, from the circumstances which attend large objects when seen at a distance on the surface of the sea. For when a ship proceeds to sea, 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, in other cases.

Again, the earth is proved to be nearly spherical in this manner: its roundness permits us to see only a very little extent of its surface: for upon a level space, for instance, a calm sea, the eye elevated six feet above it, cannot perceive an object placed upon it at a distance greater than 2557 fathoms; that is, it cannot discern more than the extent of a circle of 5114 fathoms diameter. But the circumference of this circle appears to touch the heavens, and the plane of this circle extended to the starry heavens is what is called the *horizon*. If the observer were placed in the centre T (Pl. XXIX. fig. 122.) of the earth, the horizon H H would divide the sphere into two parts; but being placed at the surface *a*, the superior and visible hemisphere *h* Z *h* is smaller than the inferior *h* N *h*, which is invisible. It may yet be observed, that the radius of the earth T *a* being infinitely small, compared with the imaginary radius of the starry heavens T H or T Z, the difference between the two horizons, with respect to them, is not perceptible. When the first, therefore, is called the *rational*, and the other the *sensible* horizon, which are the names by which they are distinguished, it must be with reference to nearer objects.

Many other proofs might be adduced to show that the earth is nearly spherical; nor are the little unevennesses on its surface, arising from hills and valleys, any material objection; since the highest mountains with which we are acquainted bear a less proportion to the whole bulk of the earth, than the small protuberances on the coat of an orange bear to that fruit. 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; and this also affords a further proof of the spherical form of the earth; since no body but a sphere can in all positions project a shadow with a circular boundary. In speaking of the earth, however, when I use the term *spherical*, I would not be understood to indicate that it is a perfect globe or sphere. The most correct observations, on the contrary, prove that it is an oblate spheroid, that is, a little flattened at the poles, and larger about the equatorial regions, somewhat resembling (if we may use so homely a comparison) the form of a turnip.

The earth's axis makes an angle of nearly $23\frac{1}{2}$ degrees with the axis of its orbit, and keeps always the same oblique direction inclining towards the same fixed stars throughout its annual course; and this causes the return of Spring, Summer, Autumn, and Winter, as will be shown in a future lecture.

The mensuration of the earth has been attempted by different persons, with different degrees of precision. Mr. Richard Norwood, in the year

1635, 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 as exact a manner as he was able; and having taken into the account all the windings of 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; and this distance, being compared with the difference of latitude, gave him five thousand two hundred and nine chains to a degree, or about fifty-seven thousand three hundred French fathoms or toises.

This method requires no explanation, if the two places are considered as lying under the same meridian, which indeed is nearly the case. The same operation 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 makes with a third, the triangle formed by the three objects will become known; so that the 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 give the measure of the whole. But by applying the telescope to the quadrant, and furnishing it with a micrometer, we are enabled to correct a great many inaccuracies attending this kind of mensuration. 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 measure of national honour and importance. Monsieur Picard was the person employed to perform this business. He began by measuring the distance between Villejuif and Juvisy; and this base, which he found to be five thousand six hundred and sixty-three fathoms, was that 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 windmill 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 fathoms. 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 fathoms. 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 Maree; and from all these measures, the distance between Mareil and Malvoisine was found to be thirty-one thousand eight hundred and ninety-seven fathoms French.

In a similar 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 fathoms. But as calculations are less subject to errors than mechanical operations, Mons. 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 mensuration; and as these exactly agreed, he could no longer doubt of the truth of his former calculations. For the two bases were separated by so large a distance, that it was impossible for them to correspond, except by a perfect exactitude in all the intermediate steps.

This part of his project being finished, he had now to reduce the distance between Sourdon and Malvoisine to an arc of the meridian.

Having obtained this terrestrial distance to a great 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 fathoms upon the earth, he concluded, by the rule of proportion, that the length of a degree, in that latitude, must be fifty seven thousand and sixty-four fathoms. 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 fathoms, he took a mean between the two, and fixed his degree at fifty-seven thousand and sixty, or about sixty-nine and a half English miles.

The surveys were all taken upon a supposition that the earth was a perfect sphere; but the truth of this doctrine was soon called in question as the science advanced. Newton and Huyghens had shown, from the known laws of gravitation, that the true figure of the earth must be 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 dispute, it was ordered by the French king that a degree should be measured, both at the equator and 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, Bouguer, 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 Gulf of Bothnia, on the 8th of July 1736, and finished them about the beginning of June 1737. M. Maupertuis, soon after their return to France, published an exact and interesting account of all their transactions.

The result of this measurement was found to be, that an arc of the meridian contained between the parallels of Tornea and Kittis was equal to fifty-five thousand twenty-three and a half fathoms. And as the magnitude of this arc was found, by means of the zenith distances of certain fixed stars, to be 57 minutes 28 and 2-3ds seconds, it was determined, after proper corrections, that the true length of a degree of the meridian which cuts the polar circle is fifty-seven thousand four hundred and twenty-two fathoms.

Those 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 twelve months before the former, and did not finish their survey till the year 1741. The province of Quito was the place determined on as the most proper for their purpose. Here they measured an arc of the meridian, of three degrees seven minutes and one second, and found it to contain 176,950 fathoms; which being reduced to the level of the sea, and properly corrected, the first degree of the meridian from the equator was found to be equal to 56,753 fathoms. These measures afford a decisive demonstration that the earth is flattened at the poles, and protuberant at the equator. For had the figure of it been a complete globe, as was formerly imagined, a degree of the meridian in every latitude would have been found the same; and had the figure been that which was given to it by Cassini, a degree at the polar circle would have been less than a degree at the equator. But as a degree at the equator appears to be about 307 fathoms less than a degree in France, and about 669 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 was assigned it by Newton.

Subsequent admeasurements carried on upon a large scale, and with great accuracy, in England and Scotland, by Roy, Mudge, and Colby; in France by Delambre, Mechain, Arago, &c.; in Denmark by Schumacher; in Lapland by Swanberg; and in India by Lambton. Though they are attended by certain minute irregularities, all tend to confirm the general result that the axes of the earth are in about the ratio of 304 to 305.

Experiments on the pendulum in different places, as, by Bouguer at the equator, Campbell at Jamaica, Ciscar at Madrid, Borda and Biot at Paris, Whitehurst and Kater at London, Biot at Leith and Unst, Dr. Olinthus Gregory at Woolwich, and in Balta Isle, Zetland, and Lord Mulgrave at Spitsbergen; all prove, generally, that the equatorial axis exceeds the polar axis. A synoptical account of the results, agreeably to this latter method, is given in Tilloch's Philosophical Magazine for June, 1819.

There is nothing of more importance to a naval people than the power of ascertaining the longitude at sea. This problem is ultimately resolvable into that of knowing the precise hour at the place where the mariner is, and the precise hour at any other place the longitude of which is well ascertained—London, for instance. It is easy to find the hour at any place where the mariner may happen to be, by observing the height of the sun or of any fixed star; and observations on the eclipses of the satellites of Jupiter show the hour by the clock of London at the time when they are observed; the difference, then, between the times observed at the different places, will give the difference of longitude. This is the reason why a clock or time-piece which does not vary at all, and which is set to the time of the place from which a vessel sails, will always serve to show the difference of time between whatever place it may be at, and that of the place which it has left, and consequently will indicate the longitude, provided it goes accurately.

To render this matter still more familiar, 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 15 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 all those places which lie under the meridian 15 degrees to the east of that of London; and eleven o'clock in the morning, at all those places which lie under the meridian 15 degrees to the west of that of London. If the distance of the meridians are 30 degrees, it will make two hours difference in the time; if 45 degrees, three hours, &c., reckoning according to the situation of the places.

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 15 degrees in longitude always producing a difference of one hour in the time shown by those machines.

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 the pupil was at sea, and wanted to find the longitude of the place he was in: he chooses some remarkable fixed star, whose name and situation are known, and finds 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, he looks into the almanac, and finds 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 15 degrees to an hour, give the longitude of the place required. The names and places of the brightest fixed stars are to be found in the " 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 observed, 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 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 by a person of skill and abilities the operation will be performed in a few minutes.

In the first place, then, it may be observed, that the moon's daily motion in her orbit being about 13 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 is committed in calculating the place of the moon, it will produce an error of two minutes in time, or half a degree of longitude.

The late Professor Mayer, of Gottingen, following the theory of Newton, formed a set of lunar tables which gave the moon's place in the heavens to a great degree of accuracy; and these were afterwards improved by Mr. Charles

Mason, so as to determine the distance of the moon from the sun or a fixed star at any given time within little more than half a minute of a degree.—This difference from the truth cannot subject us to an error in longitude of much more than a quarter of a degree, or 15 geographical miles.

It will conduce to a greater degree of accuracy, if the moon's distance is 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 is taken separately.

Observations upon the eclipses of Jupiter's satellites, the times of which are recorded in the *Nautical Almanac*, and in that much more correct Almanac, *White's Ephemeris*, serve likewise to determine the longitude with considerable precision. But, for a minute explication of these and other methods, the reader will do well to consult Dr. Mackay's work, written expressly on the subject.

LECTURE XXII.

ASTRONOMY.

THE TIDES.

As a phænomenon affecting this earth, the consideration of the tides will properly follow what we have advanced on that subject. It is almost unnecessary to explain to you what is meant by the word tide. If a definition were called for, it might be said that it is a daily regular and periodical rising and falling of the waters of the sea.

In great oceans this rising and falling, in other words the flux and reflux of the sea, take place twice a day. That is, about every six hours the waters of the ocean extend themselves over its shores: this is called the *flux* or flood; in this state they remain a short space of time, after which they retire or fall back; and this is called the *reflux*, or ebb tide.

During the flood tide the waters of those rivers which communicate with the ocean are stopped in their course by the advance of the sea water; the rivers swell, and overflow their banks; during the reflux or ebb tide the stream resumes its usual course.

Where the motion of the waters is not retarded by capes, islands, or straits, or other similar obstacles, three periods are remarkable in the tides—The daily period, the monthly, and the annual.

The mean daily period is 24 hours 49 minutes, during which there are two flood and two ebb tides. This interval of 24 hours 49 minutes is the time in which the moon performs her mean apparent daily revolution round the earth. During this diurnal period we observe,

1st, That the high tide reaches the Eastern harbours and roads, sooner than those to the West.

2dly, That between the tropics the tide always seems to proceed from East to West.

3dly, That in the torrid zone, unless there is some particular obstacle, the flood tide comes regularly at the same time to all places under the same meridian. On the contrary, in the temperate zones it comes sooner to a lower than to a higher latitude; but beyond 65° of latitude the tide is not sensible.

The monthly period is distinguished, 1st, by this circumstance, that at the new and full moons the tides rise much higher than at other periods; and these are called *spring* tides; and when the moon is in the quarters, the tides are lowest, and are called *neap* tides. The new and full moons are called the syzigies, the quarters, the quadratures: the tides go on increasing from the quadratures to the syzigies, and decreasing from the syzigies to the quadratures.

2dly, When the moon is in the syzigies or quadratures, the tide is at the highest three hours after the moon has passed the meridian. When the moon is going from the syzigies to the quadratures, the time of high water is rather sooner than these three hours. The contrary happens when the moon passes from the quadratures to the syzigies.

3dly, Whether the moon be in the southern or the northern hemisphere, the time of high tide does not happen any later in northern climates.

The annual period is distinguished by these circumstances:—1st, That at the time of the equinoxes the spring tides are higher than at any other season of the year, and the neap tides the lowest, because at these periods the sun and moon are in the equator. At the solstices, on the contrary, the spring tides are not so high as in other lunations; nor the neap tides so low as at other periods. The tides also are higher at the winter than at the summer solstice.

2dly, The tides are higher in proportion as the moon is near the earth, that is, when she is in her perigé. They are also higher when the moon is near the equator, and has of course less declination. In general, then, it may be said, the highest tides are when the moon is at once near the equator, in perigé, and in the syzigies.

3dly, In northern climates the spring tides are higher in the evening during winter; and in the summer they are higher in the morning *.

It is evident from the detail of these phænomena, that the tides have a marked connexion with the motions of the moon; and that they are also in some degree governed by those of the sun. Whence we may fairly conclude that these luminaries, and particularly the former, are the principal natural causes of the phænomena of the tides.

Kepler had long ago conjectured that the gravitation of the earth towards the sun and moon was the cause of the tides. "If the earth ceased," said he, "to attract the waters of the ocean, they would be elevated towards the moon; for the moon's sphere of attraction extends to our earth, and evidently acts upon the waters." What was mere conjecture in this great astronomer was reduced to certainty by the superior genius of Newton: upon his principles, therefore, I shall endeavour to exhibit a popular view of the theory of the tides.

* The days on which the highest tides may be expected are always given in *White's Ephemeris* before mentioned. That very useful almanac also exhibits the time of morning and afternoon high water daily, as computed accurately for London Bridge; with subsidiary rules, by which the respective times of high water at several other ports may readily be found.

The surface of the earth and of the sea is so nearly spherical, that it may for the present be regarded as such. This being granted, if we imagine the moon A (Pl. XXIX, fig. 121) situated in any part above the surface of the sea at E, it is evident that the water E will be attracted by her more in that point than any other in the whole hemisphere PEH; there will of course be a tide at E.

For the same reason, the water at G will be less attracted by the moon than any part of the sea in the hemisphere PGH. The water then at this part will be less affected by the moon than at any other; it will be therefore elevated on the opposite side, and this will make a tide at G.

By these means the surface of the whole ocean will assume an oval form, the longest diameter of which is EG, and the shortest PH. As the moon then changes her position, by the earth's diurnal motion, this oval figure will follow the apparent place of the moon; this therefore will produce two tides in the course of 25 hours, as before established.

Such is the general theory of the tides. But to explain it more fully, let us suppose the moon to be at rest, and let us imagine the earth to be a solid globe also at rest, covered however to a certain depth with a homogeneous fluid, the surface of which shall also be spherical.—Suppose the particles of this fluid to gravitate, as in fact they do, towards the centre of the earth, at the same time that they are attracted by the moon. It is then certain that if all the particles of the fluid with which the globe is covered were attracted by an equal force and in a parallel direction, the action of the moon would produce no other effect than to move or displace the whole mass of the globe and of the fluid together, without causing any other derangement in the respective situation of their parts.

But, according to the laws of attraction, the parts of the superior hemisphere, that is, of that portion which is nearest the moon, are more forcibly attracted than the centre of the globe; and on the contrary, the parts of the inferior hemisphere are less forcibly attracted. It follows, then, that the centre of the globe being moved by the action of the moon, the fluid which covers the superior hemisphere, and which is attracted more forcibly, must have a tendency to move more than the centre, and consequently to rise with a force equal to the excess of this attraction above that which acts upon the centre. On the contrary, the fluid which is expanded over the inferior hemisphere being less attracted than the centre of the globe, will have a less tendency to the same point. It will of course have a kind of centrifugal force, nearly equal to the force which attracts that of the superior hemisphere. Let us then suppose that the moon A, by the force of her attraction, draws towards her the centre T to the extent of 20 feet, and brings it to *t;* that the part E being nearer to the moon, and still more forcibly attracted, is carried to the extent of 30 feet; and that the point G being more distant from the moon and more feebly attracted than the centre T, is only drawn as far as *g* to the extent of 10 feet; it is evident that the radii * *t e* and *t g* must be longer by 10 feet than the radii TE and TG. The waters therefore must appear elevated to that extent, while they are lowered at *p* and *h*. Thus the fluid (as appears evidently by the figure) will be elevated at two opposite points in the line AG, in which line are the centres of the earth and the moon. If further the attraction of the sun is added to that of the moon, the former being about a third of the latter, the effect will be proportionably greater; but if these two attractions are placed in counterpoise to each other, the effect will be proportionably less.

The motion of the waters of the sea (at least that of which we are sensible, and which is not common to them with the whole mass of the terrestrial globe), is not the effect of the entire action of the sun and moon, but of the difference between the action of these luminaries upon the centre of the earth, and upon the fluid with which it is covered, as well on the upper as the lower surface. It is this difference which we

* The radius is a line from the centre to the circumference of any circular figure.

call action, force, or attraction, solar or lunar. The lunar action, as just noted, is thrice as energetic as that of the sun.

I shall now deduce from the doctrines which have been advanced, what I hope will be found a clear and convincing explanation of the principal phænomena of the tides.

We have seen that the waters of the ocean must rise at the same time at that part of the ocean which is immediately under the moon, and at the opposite point. Consequently, at ninety degrees from these points on each side, the water must be lowered. In the same manner the solar action must elevate the waters in that part which is immediately under the sun, and at the part diametrically opposite. Combining the two actions, we shall find that the elevation of the water at the same place must be subject to some variations both with respect to quantity and time, according as the solar and lunar actions are combined; or according as these forces act differently, or against each other.

In general, in conjunctions and oppositions of the sun and moon, their forces are combined. In conjunctions these bodies act on the same meridian; and in opposition, they still act in the same line, and each raises the water on that side which is immediately under it.

In the quadratures, on the contrary, the water which is elevated by the sun, is depressed by the moon's attraction, for the moon is then ninety degrees from the sun. This, then, is the time of the lowest or neap tides; and the highest or spring tides happen at new and full moon, when the two luminaries are in conjunction or opposition.

In the course of every natural day there are two tides, which depend upon the action of the sun, as in every lunar day there are two which depend on that of the moon; all follow, however, the same laws. In general, the nearer the moon happens to be to the earth, the greater is its attraction, and the same may be said of the sun.

Laying aside for the present the action of the sun on the ocean, the highest tide would be at the moment when the moon passed the meridian, if the waters had not, like all bodies in motion, a *vis inertiæ*, by which they are inclined to retain the impression they have received. But this force must necessarily produce two effects. It must retard the time of high water, and it must in general diminish the height of the tide. As a proof, let us for a moment suppose the earth at rest, and the moon above it in a certain point. Abstracting, then, the action of the sun, the force of which upon the tides is much less than that of the moon, the water would unquestionable rise in that part which was under the moon. Let us suppose again that the earth turns upon its axis: on one side it turns very rapidly as to the motion of the moon; and on the other, the water which has been raised by the moon, and which turns with the earth, endeavours (if we may use the expression) to preserve by its *vis inertiæ* the elevation which it has acquired, though in withdrawing from the moon it loses somewhat of that elevation. Thus the water carried forward by the motion of the earth on its axis will be elevated more to the east of the moon than it would have been without this motion; yet it will at the same time be less elevated than it would have been directly under the moon, had the earth continued immoveable. The motion of the earth on its own axis, then, has in general a tendency to retard the time of high water, and to lessen its elevation.

Both after the flux and reflux, the ocean continues some time quiescent, neither disposed to rise nor fall, because the waters have a tendency to preserve the state of rest and equilibrium in which they are at the flood and ebb tide; and because the motion of the earth, displacing the waters with relation to the moon, lessens the intensity of the action of that luminary. These two efforts counterbalance each other for some moments. We must add also, that the attraction of the particles of the fluid to each other, and obstacles of different kinds, which must retard their motion, prevent them from passing all at once from a state of flood to that of ebb.

The moon passes above the eastern parts of the globe before the western. The flood tide, therefore, always proceeds in this direction. But the *general* motion of the sea between the tropics from east to west is more difficult to explain. This motion is evinced by the direction in which all floating bodies proceed there. It is observed also that, all other things being equal, it is much easier to navigate towards the west than in the contrary direction. M. D'Alembert has demonstrated, in his Inquiry into the Causes of Winds, that the action of the sun and moon must cause a motion in the waters under the equator from east to west. This action must, according to the same writer, equally affect the air, and is one of the principal causes of the trade-winds.

If the moon remained always in the equator, it is evident she would then be always ninety degrees distant from the poles, and that there could be *there* neither flux nor reflux; for the waters at the poles would always be low. Though the moon, however, is not always in the equator, she is never more distant from it than twenty-eight degrees. We are not to wonder, therefore, that near the poles, and even at the latitude of sixty-five degrees, the tide is not perceptible.

As it only happens twice in a month that the sun and moon are in the same line or direction, (that is, when they are in conjunction or opposition,) the elevation of the water ought in general to take place neither immediately under the sun nor under the moon, but in a point between the two, as in truth we find to be the case. Thus, when the moon passes from the syzigies to the quadratures, (that is, when she is not ninety degrees from the sun,) the highest elevation of the waters ought to take place at the setting of the moon;—the contrary happens when the moon passes from the quadratures to the syzigies. In the first case the time of high water ought to precede the three lunar hours: for on one side the *vis inertiæ* of the waters produces the elevation three hours after the moon passes the meridian; and on the other, the relative situation of the sun and moon affects this elevation before the moon passes the meridian. On the contrary, in the second case, and for similar reasons, the time of high water must happen rather after the three hours.

As there is some retardation of the tide by the *vis inertiæ* of the waters, and their tendency to preserve an equilibrium, the highest tides do not take place exactly at the time of the oppositions and conjunctions of the sun and moon, but two or three tides after. In the same manner, the lowest neap tides happen a little after the quadratures.

Since in the winter the sun is a little nearer the earth than in the summer, it is observed that, when all other circumstances are equal, the tides about the winter solstice are rather higher than those of the summer solstice.

Such would be the regular phænomena of

the tides, if the sea were, in all parts, of the same depth; but the shoals in certain parts, and the narrowness of some of the streights and channels, cause a great variety in the height of the tides; of which it is impossible to give an account, without an exact knowledge of all these irregularities, the relative situation of the shores, the depth of the channels, &c.

At the mouths of rivers, the flood tide and the tide of ebb exhibit different phænomena. The current of the river resists the flux of the sea, but aids its motion at the reflux; whence the tide of ebb lasts considerably longer than the tide of flood. This is the reason, too, why high water takes place at a later hour in great rivers than elsewhere. But the diversities of ebb and flow in different localities are too numerous to be traced in our narrow limits.

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