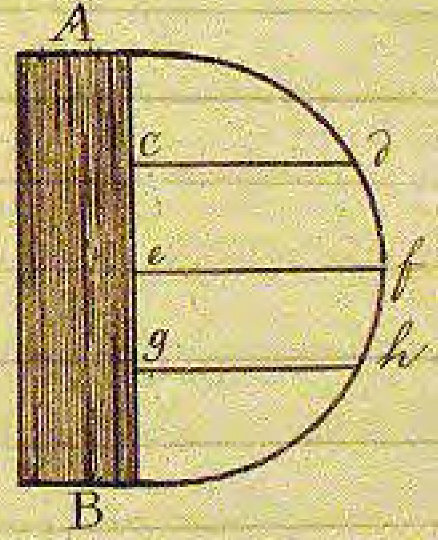
doctrine of falling bodies. Suppose a vessel of water divided into any number of equal parts these parts pressing on each other, the first on the second with only its own weight, the second on the third with double its weight, &c. This resembles a body falling through any hight; at the first distance it acquires a velocity sufficient to carry it through double the space it has fallen, at the next station, a velocity sufficient to carry it through double this last space, &c. The quantity of water discharged through pipes of different lengths but of the same bores, is inversely as the squares of the distances. The hight to which fluids can rise when conveyed from any fountain, is equal to the hight of the level of the fountain from whence they flow: but when they are designed to be raised higher, forcing engines must be used, which will be described hereafter. The Romans conveyed their water through aqueducts for 5 or 6 miles: if they met with mountains in their way they cut through them: but if they had been acquainted with the principle above mentioned, they might have spared a great deal of unnecessary labour.

In order that twice as much water should run through one orifice as through another, it must be four times as far below the surface as the other; and so on. If the vessel AB be filled with water, of which e is the centre, the water will spout horizontally from the orifice e double the



distance A e or e B: if equal distances be taken above and below e, as c and g, the water will spout from the orifices c and g to exactly the same distance, from the one as the other. In other words if e be the centre, and a semicircle be described about it of which e A is the radius, the water will spout from the orifices to double the length of the sines of the arches; that is from the orifice c, the water will spout double the sine c d; from e to double the sine e f; and from g to double the sine g h.

Lecture XXIX.

Of Hydraulics.

I. Of Pumps.

Before we speak of pumps it is necessary to know, that hydraulics is a science which has for its object the motion of fluids, and the construction of machines dependent on them. The nature of springs, and the theory of tides, are comprehended under this definition. The motion of fluids is caused, 1st. By their relative gravity or pressure; which is the most natural motion. 2. By the pressure of the air upon the surface of fluids. 3. By the spring or elastic power of condensed air. 4. By the force or pressure of a piston. 5. By attraction, as that of capillary tubes.

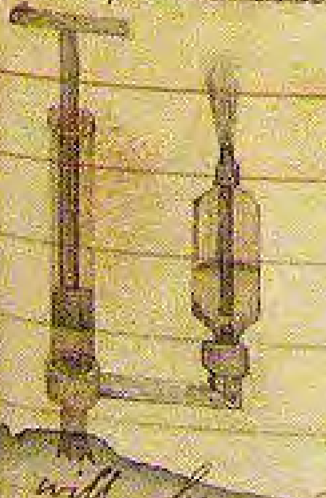
Pumps may be generally divided into two kinds; the common pump, or (as it is usually, tho' improperly, called) the sucking pump; and the forcing pump, which is again subdivided into two kinds. We speak of them in order.

The common pump is a machine both pneumatic and hydraulic, is of very simple construction, and may be easily explained. The figure in the margin represents a common pump. CB is the lever by which

it is worked. G is the water into which it is immerged. CG is the pump pipe. In the bore CD works a piston Cc; the end of which exactly (or ought to does) fits the bore. In that end there is a valve, c. At F there is another valve, a. When the piston is drawn up by means of the lever CB, the air in the part of the bore DF is thereby attenuated; in consequence of which the air in the pipe FG wishes to restore the equilibrium thro' the valve, a. When the piston descends it presses the air upon the bottom F and closes the valve, a. Then the valve, c, is pressed upwards and the air rushes thro' it. When the piston is again raised the valve, c, shuts; the valve a, opens; the air rushes from the pipe FG; and becomes more attenuated than before. At length a vacuum is formed in the pump. The pressure of the atmosphere upon the surface in the vessel G, drives the water up the pump DG thro' the valve, a, and when the piston comes down, thro' the valve, c; after which the water is raised by the working of the piston, the lower valve still admitting water and preventing it from going out, alternately, as the piston rises and descends. But as the pressure of the atmosphere can only drive water 33 feet, the upper valve must always be within that distance from the surface. If however another pump be made to work in the reservoir, c, the water may be raised double that height, and by similar means, to quadruple, &c. —

The force required to work a pump will be as the height to which the water is raised, and the square of the diameter of the pump bore, in that part where the piston works. So that, if two pumps be of equal heights, and one of them be twice as wide in the bore as the other, the widest will raise four times as much water as the narrowest; and will therefore require four times as much strength to work it. The piston is always raised by a lever; the arm by which the pump is worked being 5 or 6 times as long as that fixed to the pump rod; which gives the working power a considerable advantage. Upon these principles, it will be easy to find the dimensions of a pump which shall work with a given force, and draw water from a given depth. — Mr Booth has drawn up a table for that purpose which may be seen in Ferguson, Lecture 5.

The forcing pump is of two kinds, and is also partly a pneumatic and partly a hydraulic machine; I shall describe both kinds. In the first (fig. 1.) the water is raised thro' the valve, c, as in the common pump; but as there is no valve in the piston D it goes along the canal cE, and thence is driven up the tube E a, and by being pressed by the piston is forced to spout out at, a, which it will do at every stroke of the pump.



In the other kind, the water (fig. 2 is brought in the same manner into the tube c a, but when it gets above the end, c, of the little tube c a, the air in the large tube will be condensed, and by its spring will cause the water to spout out in a continued stream. —

If the lever of one of these pumps be fixed to the cranked axle of a wheel (as the lever BD is fixed to the cranked axle AC of the wheel c), every revolution of the wheel will work the pump, and the wheel may be worked by a running stream of water, or by horses.

Fig. 3 is a representation of Archimedes's screw, a machine for raising water. It depends upon the principle, that water always endeavours to occupy the lowest point. As the screw turns round the water is continually falling to the lowest part of it, and by that means at length arrives at the top.—

There is another mode of raising water by means of a rope. The rope goes over two pullies, the one under the water, and the other fixed at the height to which the water is to be raised: then by pulling the rope around them, it carries the water, thro' which it passes, in small quantities up with it. This, however, must be a very slow way of raising water.

A forcing pump may be worked by means of steam, which is extremely elastic, but is immediately condensed by means of cold. The steam in the boiler A pushes up the lever DC; the piston C of course descends: a drop of cold water let in at the cock E condenses the steam in the boiler, upon which that end of the lever descends and draws up the piston C. So the pump is worked— This is the manner in which the steam engines are formed. The pump in which the piston works is a forcing pump and will discharge vast quantities of water. The machine is used to extinguish fires. Its principal parts are. 1. The boiler. 2. The cylinder. 3. The beam or lever. It depends upon the following philosophical principles. 1. Water may be converted into steam by heat. 2. It is easily converted into water by cold. 3. When converted into steam it is extremely elastic. 4. The pressure of the atmosphere. The steam acting against a piston fixed to one end of a moveable lever causes it to ascend; and a piston fixed to the other end which works the pump, causes it to descend. The steam being condensed, the pressure of the air on the first piston causes it to descend, and of course the other which works the pump to ascend; and thus the water is raised by the alternate action of each piston.

The action of the common pump depends on the pressure of the atmosphere, which causes the water to rise and follow the piston as it is drawn up.

Of the two kinds of forcing pumps, one depends on the condensation, the other on the refraction of the atmosphere.

Forcing pumps by running streams, depend on the force of the fall of the water, and the height to which the water is intended to be raised by the engines.

Origin of springs.

Various have been the theories, or rather hypothesis, relating to the origin of fountains, many of which have savoured so little of philosophy, that they scarce deserve to be mentioned or confuted. Those who pretend to derive the waters of springs from the waters of the sea by subterranean ducts, seem either wholly ignorant of the hydrostatic laws of fluids, or resolved to maintain a theory by mere dint of hypothesis: besides they should inform us how the waters lose their saltness by their conveyance through these ducts.

They who advance the capillary hypothesis, or suppose the waters rise from the depths of the sea thro' the porous parts of the earth, as it rises in capillary tubes, or tubes of sand or ashes, seem not to consider one principal property of this kind of tube, or this sort of attraction; for though the water rise to the top of the tube or sand, yet will it rise no higher, because it is by the attraction of the parts above that the fluid rises, and where that is wanting it rise no farther. Therefore, tho' the waters of the sea may be drawn into the substance of the earth by attraction, yet can it never be raised by this means into a cistern or cavity to become the source of fountains.

The true principles which supply the waters of fountains or springs are undoubtedly melted snow, rain water and condensed vapours. Several have attempted to solve the phenomena by snow or rain only; but others making an estimate of the quantity of rain and snow, that falls in the space of a year, to see if it would be equal to that which the rivers discharge annually into the sea, found that it was much short of that quantity.

But that which was most extraordinary was, that they found by their experiments, that the rain and snow which fell in one year would not produce more than $\frac{2}{3}$ of what was raised in vapours for by experiment it was found, that the rain and snow that fell in a cylindric vessel, raised a column of water about 19 inches high; whereas the water raised in vapour was yearly about 32 inches in altitude. This great deficiency of 13 inches plainly indicated another way, by which the waters circulated to and from the sea.

This (among many other things) was left to the discovery of that sagacious naturalist Dr. Halley; who being on the tops of the mountains in the isle of St. Helena (in South lat. 16°) making his observations for a catalogue of the southern stars, — (about 800 yards above the level of the sea) found that the quantity of vapour, which there fell in dew, was so great, as very much impeded his observations, by covering his glasses over in 6 or 7 minutes, even when the sky was clear.

Upon this he was induced to determine by experiment, the quantity of vapours raised from the surface of the sea, as far as it arises from the heat of the sun only. For this purpose he instituted the experiment in the following manner: he took a vessel of water, and made it salt to the same degree with sea water, by means of the hydrometer. In this he placed a thermometer, and by a pan of coals he brought the water to the same degree of heat with that of the air in the hottest summer.

This done, he affixed the vessel of water, with the thermometer in it, to the end of a pair of scales, and nicely counterpoised it with weights in the other; then at the end of two hours he found by the alteration made in the weight of the vessel, that about the 60th part of an inch of the depth of the water was gone off in vapours, and therefore in 12 hours, one tenth of an inch would have been evaporated.

Upon this supposition, every 10 square inches of the surface of the water yields in vapour, per diem, a cubic inch of water, which weighs 253$\frac{1}{3}$ grains troy; therefore every square foot will yield $\frac{1}{2}$ a pint wine measure; every space of 4 feet square, a gallon; and every square mile 6914 tons. A degree square (reckoning 69 English miles to a degree) will produce 33 million of tons; and if the mediterranean be 40 degrees long, and 4 broad (the narrow parts compensating for the broader) which is the least that can be supposed, there will there be in its surface 160 square degrees, which will evaporate per diem, 5280 millions of tons in the summer time.

The mediterranean receives water from the following nine great rivers, viz. the Iberus, the Rhone, the Tyber, the Po, the Danube, the Neister, the Boristhenes, the Tanais, and the Nile; all the rest being of no great note, and their water inconsiderable. Each of these nine rivers (together with all the smaller) are supposed to bring as much water to the sea, as is equal to ten times the water of the Thames, at least.

In order to estimate the quantity of water, which passes daily thro' the Thames, the Dr. assumes the breadth of the river at Kingston bridge (where the flood seldom reaches) to be 100 yards, and the depth 3, so that the section of the channel is 300 square yards, and allowing the velocity of the water to be at the rate of 2 miles per hour, there will run in 24 hours, the length of 48 miles, or 84480 yards; therefore 84480 × 300 = 25344000 cubic yards, which make 20300000 tons which the river thames yields per diem.

Now each of the above nine rivers being supposed to bring ten times as much as the Thames, will yield 203000000 or 203 millions of tons, and therefore all the nine will produce 1827 millions of tons; which is little more than ⅓ of the quantity (5280 millions of tons) evaporated every day from the sea. The ⅔ nearly of this prodigious quantity of water, the Dr. allows to rains which fall again into the seas; and to the rain imbibed by the low parts of the earth, and spent in vegetation in general.

The quantity of water exhausted from the mediterranean, being so much greater than what is returned by the rivers, is the occasion of the water's setting in from the ocean, to supply the deficiency, by a continual influx or stream, which before this discovery was quite unaccountable. Also, hence it appears, why the Caspian sea, tho' it receives the waters of many large rivers, is yet never liable to overflow; because the waters, brought in by the rivers, are exhausted by the sun, wind, &c. The difficulty indeed, is on the other hand, since the exhalation is so much greater than the supply by the rivers, why the sea does not appear diminished, or its waters continually wasting?

The prodigious quantity of vapours raised by the sun's heat, and otherwise, being carried by the winds over the low lands to the very ridges of mountains, as the Pyrenean, the Alps, the Appenine, the Carpathian, in Europe; the Taurus Caucasus, Imaus and others in Asia; Atlass, the Montes Lunæ, or mountains of the moon, with other unknown ridges in Africa; I say, the vapours being compelled by the stream of air to mount up with it to the top of those mountains, where the air becoming too light to sustain them, and condensed by cold, they precipitate in water, and glut down by the crannies of the stone; and part of the vapour entering into the caverns of the hills, the waters thereof gather as in an alembic, into the basons of stone it finds, which being once filled, all the overplus of water that comes thither, runs over by the lowest places, and breaking out by the sides of the hills, forms single springs.

Many of these springs running down by the vallies between the ridges of the hills, and coming to unite, form little rivulets, or brooks; many of these meeting again in one common valley, and gaining the plain ground, being grown less rapid, become a river; and many of these being united in one common channel, make such enormous streams as the Rhine, the Rhone, the Danube, &c. And it may almost pass for a rule, that the magnitude of a river, or the quantity of water it discharges, is proportional to the length and heights of the ridges from whence the fountains arise.

This beautiful account of the origin of springs and rivers has been received with universal applause and satisfaction in the learned world. I shall now add a word or two concerning the different kinds of springs which we find in divers parts of the country. But one thing I shall first remark, and that is, it has been asserted, and often taken for granted, that there are springs of water upon the very tops, summits, or highest parts of mountains; which position is contrary to the hydraulic law of fluids, by which they rise to the level of the fluid in the reservoir, but no higher; and not only that, but it is undoubtedly false in fact: for the tops of mountains have been examined by many eminent philosophers, who could find no spring there. I shall therefore conclude there never was, nor can be any such thing in nature.

The several sorts of springs observed are 1. Common springs, which either run continually, and then they are called perennial springs; or else run only for a time, or at certain times of the year, and then they are called temporary springs. 2. Intermitting springs, or such as flow and then stop, and flow and stop again, by regular alternations and intermissions. 3. Reciprocating springs, whose waters rise and fall, or flow and ebb, by regular intervals, or reciprocations of the surface.

There is one curious phenomenon of springs that is sometimes observed, and that is, that they run in dry weather, and are dry in wet weather; to account for which, we need only observe, that while the weather continues wet, the waters are gathering into the bason or reservoir where the springs have their rise, till there is a sufficient quantity to run over and make the spring play, by that time the weather being altered and become dry; during the dry weather, the remains of the last rains (for these springs proceed chiefly from rain water) are continually feeding the reservoir, and by that means supplying the spring, but by the time these are all spent, the weather again alters to wet, and the spring ceases of course, till it meets a fresh supply from the preceding rains, and so on.

Intermitting springs may be accounted for by supposing a syphon in the earth, which conveys all the water from the reservoir, after which the spring stops till the reservoir is refilled.

Mineral springs are owing to the reservoirs of water being situated where mineral ores abound, or the ducts or feeding streams running through mineral earth; for it is easy to conceive the particles of metal will mix with, and be absorbed by the water, which being saturated therewith, becomes a mineral spring or well.

Hot springs are owing to the water's running thro' places where there is iron and sulphur. Most metallic ores contain sulphur. In those springs at the mountains in Virginia, the thermometer stands at 112°.

Burning springs, which take fire at the approach of a candle, are owing to the bituminous matter which they contain: when burning they smell like pit-coal.

Petrifying springs are produced by the water's running over substances and becoming impregnated therewith.

The temperature of springs is uniform, because the earth is of an uniform temperature below the depth of 16 feet, and their reservoirs are generally that distance below the surface of the earth. They appear to us warm in winter and cold in summer, on account of the change of the atmosphere.

Lecture XXX.

On Optics.... Light.

After having developed the different phenomena produced by fluids diffused about us, and in regions near to our globe, we must now elevate our views to the consideration of light, which has its source amidst the stars, and whose action embraces the entire sphere of the universe.

In our inquiries into the works of nature every moment presents us with something new, beautiful, and instructive; but the properties of light which are now to be inquired into, will be found as we shall see, inferior to none either for their aptitude in answering the most important purposes for which it is designed, or for what is beautiful and grand. Optics comprehends whatever respects the science of light; but we see bodies in two different ways, 1. by reflected light, 2. transmitted light; hence the words Catoptrics and Dioptics. By the former we understand that science which treats of reflected, by the latter that which treats of transmitted light.

God said, let there be light, and there was light! But it is still a question what is light? It is a mere quality of bodies? or is it itself a real body, a distinct species of matter? The more philosophers interrogate nature by judicious experiments, the more are they convinced that it is a real body, but a body no less astonishing on account of its extreme minuteness than the velocity with which it moves. 1. It is a material substance consisting of particles inconceivably small, tho' of different magnitudes, thrown off from different points in straight lines with a surprising velocity: and whose intensity decreases as the squares of the distances increase.

1. That light is a material substance appears from its possessing all the properties common to matter; it is something that acts upon bodies and is itself acted upon; it is capable of being reflected, and refracted; it has motion; and these are properties which belong only to matter, at least as far as we are capable of judging with precision.

2. It is an extremely subtile fluid the extreme minuteness of whose parts, may appear evident from the following considerations. A candle in the night, when placed upon an eminence, as soon as it is lighted is seen for miles, round in whatever position the eye may be placed. The whole space of which the candle is the centre, must be filled with luminous particles, and yet no sensible diminution in the candle is observed in that short time. If we place an opaque body between the eye and the candle, it is no longer visible in the whole extent of a straight line comprehended between the eye and the flame, from whence it follows. 3dly. that the particles are emitted in straight lines, or that we see by a kind of rays or radii drawn from the centre of the flame to the place of our eye. It is for this reason that naturalists call rays of light, that light which is directed by straight lines.

The tenuity of these rays surpasses any idea we can form of them; we may compare them to geometrical lines; but they differ from them because they are material. If we make a hole thro' a card with a pin and look steadily thro' it, we may see all the objects in the 4th part of the hemisphere; or if we lie upon our backs, we may receive thro' that hole light from every star in the hemisphere. But it would be impossible to receive rays of light from so many objects thro' so small a space and without confusion, unless those rays were infinitely small, and surpassed the subtility of our minds. It is from this property that it penetrates with so much ease the most solid bodies; as glass, diamonds, and others. —

That it moves in straight lines is evident also from considering that when a hole is made in the window shutter, for instance of a darkened room; the rays of the sun proceed directly on, and make an image of the sun upon the object which interrupts them; but we never see images formed obliquely or laterally. So also we observe that the shadows of bodies are always such as are marked out by rays flowing in right lines from a luminous point. Besides what other reason can we assign than this property of light for our not being able to see thro' a bended tube?

This property evidently overthrows an opinion supported by some able philosophers; that light consists in certain undulations of an etherial fluid, sui generis, in the same manner as sound is produced in air; or that this fluid existing in the atmosphere when acted upon by an ignited body, is put into an indulatory motion in the same manner as air is when we hear a sound. Thus the sun or other luminous body is conceived to act by pressure upon this fluid, puts it into motion and by that motion communicates it to the eye. But, besides that the existence of such a fluid has never been proved, the action of an undulating fluid must produce effects very different from those of light. If light were propagated like sound, we should see notwithstanding the interposition of a wall or other solid body and also thro' a bent tube nor could shadows have the forms which they present to us.

3. The velocity of the rays of light is no less astonishing than their minuteness. The distance of the sun from us is not less than 112 000 000 miles; a space which a cannon ball with all the velocity which we could give it would not traverse in 25 years. But light passes over that space in 8' 13". This was discovered by the celebrated Reaumer, professor to Lewis 14th, by the observations which he made upon the eclipses of Jupiter's satellites. He found that these eclipses when the earth is between Jupiter and the sun were made 16' 26" sooner than when the sun was between Jupiter and the earth, which proved that light took up that time in passing over the diameter of the earth's orbit, and consequently half that time in passing from the sun to us, the sun being in the centre of the orbit. The distance of the sun from us is at least 93 millions of miles and since light passes over that space in 8", it will go at the rate of 200,000 miles per second.

But some of the fixed stars are 400,000 times farther from us than the sun a space which a cannon ball would not traverse in 10,000,000 of years, and even light itself in less than 7 years; an immense extent which the human mind can scarce seize or comprehend. What shall we say of those stars that are discovered every day? are they just formed? no they are so far distant, that although their light has been travelling ever since the creation of the world, yet it has just reached us.

4. As light is propagated in right lines, its power or intensity must decrease as the squares of the distances increase: this is plain from the very nature of all diverging lines. For a

demonstration of this see Cavallo vol. 1 Page 62. If we put a candle in a box exactly closed, but pierced with a small hole, and the rays of light produced by the candle proceed directly from the hole, and the room be dark, we may observe that if the rays cover any given space at a certain distance, at double that distance, they will cover 4 times that space: or observe at night the distance at which you may conveniently read with one candle; then remove the book to double that distance, you will find that not 2 but 4 candles will be necessary to read with equal convenience. We have this advantage in the theory of light, that the progress of this fluid is strictly geometrical; so that by setting out with a small number of its laws, we are able to determine its effects and results by methods which are precise and strict.

The velocity of light being thus established beyond contradiction, we have from hence the stronger mechanical argument to prove their extreme tenuity. We know that the momentum of a body arises from the quantity of matter multiplied into the velocity. Now supposing a ray of light only equal to the 14 millioneth part of a grain of sand; you may prove upon the principles just mentioned that it would have a force equal to that of a cannon ball of 10lbs flying with usual velocity; of course every thing even the hardest stones must be bruised to pieces. But when the light of the sun instead of wounding, nourishes the most tender and delicate parts of flowers, we must conclude that they are infinitely smaller than the size just attributed to them, and perhaps a ray of light taken from the sun to us, would not weigh a single grain. What reason have we from such considerations to admire not only the power, but wise contrivance in the author of nature; for without such tenuity in the rays of light, they would not only have been insupportable to the eye and consequently useless to all the purposes of vision, but destructive to the very creation.

From the surprising velocity of the rays of light is supposed to arise their effects in burning, melting, or consuming the hardest bodies, when they are condensed by means of a glass or other substance. For we may prove that they are not themselves hot; they will not heat water however long the focus of a burning glass be thrown upon it. They burn as powerfully when condensed by water as by a glass. But water extinguishes fire; the fire which they produce, then, is not resident in the ray itself; but may probably arise from its action upon any body, when its passage thro' is interrupted, an action which not even Albertus itself can resist.

Light and fire are so generally united that they they are often supposed to be the same. Yet many phenomena lead to a supposition that they are different from each other. The fountain of light itself seems to be different from that of fire. 2. We know that many of the phosphori, as old wood, flesh of animals, &c. give light without any of the effects of fire. The eyes of some animals shine in the dark. Many insects give so shining a light, that if two or three be inclosed in a tube we may read with ease by it. The sea when struck with the oar or agitated by the wind emits light; yet in none of these instances of light do we observe any of the effects of fire sensibly. Many modern naturalists are inclined to believe from microscopial observations, that this light in salt water depends upon insects which flow without number in it. But then we may ask, whence do the insects derive the faculty of emitting light. All these things are unknown to us. We are equally ignorant in what manner the sun darts forth those rays which seem to animate all nature; nor do we know what supplies the fountain of light with the means of repairing the constant loss it sustains. (Priestly has satisfactorily proved that since the creation the sun could not have lost more than 600 lbs of its weight which is about 2 grs. per year.) We do not know what becomes of that light which has been perpetually emanating for a number of years thro' all that space in which the heavenly bodies are suspended. Of these and many other things relative to light, we are ignorant; but still we know some of the laws to which its author has subjected it. I shall begin with those which respect its reflection and refraction.

But it will first be proper to define some optical terms. 1. Any light considered according to the direction of its motion if it be all carried in the same direction, is called a ray of light. 2. Every thing that affords a passage to light, is called a medium. 3. The inflection of a ray of light is called refraction. 4. When a ray of light proceeds from the common surface of two mediums as air and water, and instead of passing from one into the other is turned back upon the first it is said to be reflected. 5. The angle of incidence is the angle which a ray of light or the line described by it, makes with a line perpendicular to the surface at the point of incidence. 6. The angle of reflection or refraction, is that which the line described by the ray of light after reflection or refraction, makes with the perpendicular to the surface at the point of incidence. Having well understood these, let us now speak.

1. of reflection. There is no body either fluid or solid, which does not partly reflect or partly admit the light. There are more bodies which admit, than there are which reflect light. All bodies are made up of solid parts separated by pores. From this composition of pores and solid parts, a portion of light will be admitted into those apertures which are proportioned to its size, and a portion also will be stopped by the solid parts. We are not at present to speak of the cause of reflection, a question upon which philosophers are much divided; nor is it to be supposed we mean that light actually impinges upon bodies and is thrown off like other solid bodies; — that there is (this was Newton's idea) a repellent power by which it is reflected, and which is indeed the most probable idea; but we are here only to advance this general proposition; that when a ray of light falls upon a body not transparent, part of it is reflected or thrown back; a part enters and is within the body. —

The invariable law which light observes, is that the angle of reflection is equal to the angle of incidence. This is a fundamental law in optics and is capable of accurate demonstration by experiment.

Light is not reflected altogether from the first surface of any body, as Glass. It is in reality from the second surface on the other side that the greatest reflection takes place. This is the case in all quicksilvered glasses; for, when the surface is covered over with any substance thro' which the rays cannot pass or by which they are reflected, they are thrown back according to the law mentioned.

It is a remarkable circumstance relative to reflection, that if the second surface of any reflecting body, be contiguous to any transparent medium, as air, glass, &c, the rays will be reflected in greater quantities, the rarer the medium. Thus more is reflected when the surface is exposed only to air, than to water, and still more when it is exposed to a vacuum. This is illustrated by resting a piece of glass upon these three alternately. When the glass rests upon water, the image is not so perfect as when it rests upon air, nor as much so upon air as upon a vacuum.

Besides this power of reflection, we may prove that rays of light in passing near the edges of bodies, as metals, are attracted by them and turned out of their straight course; this is called reflection.

We shall finish this lecture with speaking of the refraction of light. Whilst rays of light pass on in any medium, as air, water, &c; if the medium be uniformly dense, they move in straight lines: but when they pass obliquely out of one medium into another which is either more dense or more rare, they are turned out of their straight course or as it is said refracted towards the denser medium; and this refraction is more or less as the rays fall more or less obliquely on the refracting surface which divides the medium. Refraction arises entirely from this that the rays are more attracted by a denser than a rarer medium; from which attraction every thing relative to refraction is to be deduced. In consequence of the uniform manner in which this attraction takes place, it must follow that when light goes out of a denser into a rarer medium, the angle of refraction will be less than the angle of incidence or the rays are bent towards the perpendicular. To prove this we took an empty bowl and observed the distance at which the shadow of the edge fell on the bowl; then poured water in it which bent it from its straight course: the angle of refraction was evidently less than that of incidence. Cavallo illustrates this in another method, volume 3, Page 169. On the contrary if a ray go out of a denser into a rarer medium, it will recede from the perpendicular.

If a ray fall perpendicularly upon the surface separating two mediums, it will not be turned out of a right line, by the attraction of the denser medium; because in that case it acts in the direction of the ray: the attraction in one case retards, in the other accelerates the motion of the ray, but cannot deflect it from its course.

To prove the manner in which bodies are elevated, we took a bowl in which we placed a dollar and stood at such a distance as not to be able to see it, upon pouring water into the the bowl it soon came into our view. Refraction is equally the same whether the rays pass from air into water or from water into air. When the refracting medium is water, the sine of the angle of incidence is to that of refraction as 4 to 3. In glass as 3 to 2. In general the denser the medium the greater the refracting power. Yet this rule is not universal. The particles of several different bodies act differently upon light; but they may be reduced to different classes in each of which the rule mentioned takes place. The inflammable bodies discover a greater refractive power than those which are not so, tho' they are even less denser for instance, oil has a greater refractive power, altho' it is less dense, than water. We do not know however, that they act upon light in all cases according to their density: most unctuous bodies, as oil of olives, spirit of turpentine, &c. having the same refractive power.

From what has been said, it is evident that all bodies in a denser medium than air, must appear elevated above their real situations: hence it is that a straight stick when put into water appears crooked.

The refraction which the rays of light undergo in passing from one medium to another effects considerable the time at which the sun or other heavenly body appears to rise or set. The time of rising, as of the sun, is easily found by calculation supposing its rays suffered no refraction. But observation proves that the sun rises sooner and sets later every day than the calculated time. This is a consequence of refraction; for the sun's rays coming thro' free space and and falling obliquely upon the atmosphere, it acts upon them as a denser medium, refracts or bends them down towards the earth, and as we always see in straight lines, the sun necessarily appears before he is above the horizon. The refraction will be in proportion to the obliquity with which the ray falls upon the top of the atmosphere. To such places as the sun is perpendicular, there will be no refraction. but to all places at the time of sun rise or sun set the refraction must be very sensible, and therefore the sun will appear to rise so much sooner & set so much later as is equal to the refraction which is equal to two minutes of time. &c

Lecture XXXI.

Colours.

Some rays are much more easily bent out of their course than others owing to their different sizes.

Homogeneous rays are those which possess the same degree of refrangibility.

Heterogeneous rays are those which possess different degrees of refrangibility.

The opinion of Aristotle as to rays was the only one generally received for upwards of 200 years. He supposed that the rays of light were an uniform substance; but this theory is entirely exploded and has given way to the more rational theory of Sir Isaac Newton which is that colour proceeds altogether from the rays of the sun.

There is a general proposition under which we prove that this proposition comprehends several others each of which has been sufficiently demonstrated by Sir Isaac Newton. 1. That the rays of light are not homogeneous but heterogeneous. They are heterogeneous because they possess different degrees of refrangibility. 2. That each species is disposed to suffer a different degree of refraction and to excite the idea of a different colour. That they suffer a different degree of refraction is proved by their separation when they pass thro' a prism. if any one of these rays be reflected from any body, that body will appear to be of that particular colour in all cases. 3. That the colour of each species is unchangeable. This is proved by throwing any number of these separate rays on a prism; for they will remain unaltered after any number of refractions.

A prism is any solid body thro' which the rays of light, in passing, are separated. The separation is owing to the different sizes of the particles of light, by which they suffer a different degree of refraction, and of course after passing thro' the prism are separated.

The primary colours are red, orange, yellow, green, blue, indigo, and violet.

If the space filled by the colours be divided into 360 equal parts, the red will occupy 45, the orange 27, the yellow 48, the green 60, the blue 60, the indigo 40, and the violet 80. It is remarkable that the proportion of colours exactly coincides with the harmonic scale.

The colour of any given ray is not altered by any number of subsequent reflections or refractions.

If the rays separated by a prism be concentered by a lens, they will form the common solar colour.

If any two or more of the separated rays be concentered, they will form a third colour, a compound of both, and different from both.

The variety of colours observable is accounted for from the most satisfactory experiments.

The difference in the size of the particles of light is inferred from their being differently refrangible, which is owing to their being attracted out of their course; this difference in refrangibility can only arise from difference in size since they have the same velocity. Some are more agreeable to the eye than others, because they have a less momentum, and of course do not irritate the retina of the eye so much.

Whiteness is produced by mixing together all the different colours of which the colour of the sun's rays is compound, and then taking away the yellow.

By mixing together any two of the prismatic colours separated by an intermediate one, the latter will be produced.

Black is the absence of all colour and is the hottest because it absorbs the greatest part of the sun's rays.

The same bodies appear of different colours because they reflect one kind of rays and transmit another: when seen by the reflected rays they appear different from what they do when seen by the transmitted rays. They appear also to transmit different rays according to their different situation.

Some bodies reflect one kind of rays and some another; which is owing to the difference in their texture.

The opacity of bodies arises from their porosity; their pores being filled with bodies of different density from their own, the rays suffer so many refractions and reflections that they are lost before they come out. This is proved by a number of glasses being laid on each other on a piece of writing till the letters disappear, then by putting water between them (which has nearly the same refractive power) the letters will then become visible. Great hardness is necessary for transparency.

Lecture XXXII.

I. Of the manner in which rays of light are refracted in passing through glasses of different forms.—

The subject of optics is divided into dioptrics and catoptrics. The first treats of vision and transmitted light; the second of reflected light.

Parallel rays are those which always keep at the same distance from each other. Diverging rays are those which issuing from the same point continually recede from each other. Converging rays are those which continually approach each other.

The real focus is that in which the rays, being made to converge, do actually meet. The imaginary focus is that in which they would meet if not intercepted. Sometimes the rays are so reflected that they proceed afterwards as from some point which is not their true radiant point.—

A lens is a medium terminated on one side by a spherical surface and on the other by a plane or spherical one.

There are 5 kinds of lenses, viz. 1. The double convex. 2. The plane convex. 3. The double concave. 4. The plane concave. 5. The convex concave.

The double concave causes rays to converge, and if they be parallel to converge to a focus at a distance equal to the radius of the glass's convexity. The plane convex causes rays to converge with a force equal to half that of the double convex: parallel rays are therefore brought to a focus at twice the distance viz. at a distance equal to the diameter of the glass's convexity. The double concave causes rays to diverge: if the rays come from the imaginary focus of parallel rays they are made to go on parallel after passing thro' the glass: the plane concave has the same effect upon rays, but its force in that respect is equal to half the power of the double concave. The meniscus causes parallel rays to converge.— The physical cause of these different properties is attraction.

The focal distance of a plane convex glass is equal to the diameter, of a double convex one to the radius. But if the convexity be not the same on both sides, divide the double product of the radii by the sum, the quotient will be the focal distance.

When rays are placed at distances more than the focal distance, convex glasses do not bring them to a focus but make them diverge less.

The farther the radiant point is, the nearer the focal distance, and vice versa.

Rays passing thro' a convex glass form the image a little beyond the focal point; and as the rays cross each other in the focal point the image must necessarily appear inverted.

Convex lenses bring parallel rays to a focus; they cause convergent rays to converge more and to come to a focus sooner, and divergent rays to converge, become parallel, or diverge less.

The heat produced by convex glasses is to the heat of the sun, as the area of the glass to the area of the focus.

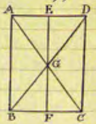
The power of burning in different glasses is as the area of the glass to the area of the focus.

The greatest effect of burning may be produced by a combination of plane mirrors.

By a combination of plane mirrors heat has been produced sufficient to vitrify copper in 8 seconds.

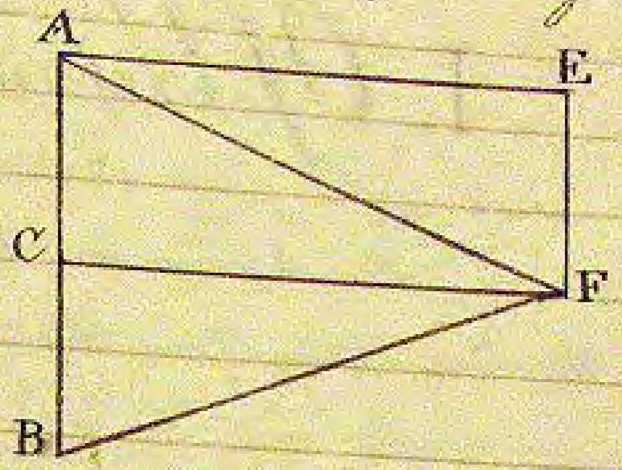
The rays reflected from the moon fall so divergent that they must be condensed a million of times to produce any sensible heat.

II. Of light reflected from different surfaces.



Let AB be an object, EG a glass; a ray BG striking the glass will be reflected to an eye at A and as we always see in straight lines, the object will appear to be placed in the imaginary focus i.e. where AC intersects BC. It is thus demonstrated. Because the adjacent angles at E are right angles, and because AGF is equal to BGE and

AGE to FGC, BGF is equal to FGC; therefore BF is equal to FC: but FC is of the distance of the image BF of the object. &c. Q.E.D.



Let AB be a man: if a ray of light AC falls perpendicularly on the mirror EF it will be reflected back to the eye in B the same straight line: if now a ray of light BF falls on the mirror, as the angle of incidence is equal to that of reflection, it will be reflected in the direction FA and will strike his eye placed at B and in the same manner all the intermediate part: and EF is equal to half of AB. Therefore &c. Q.E.D.

The solar focus is the point where parallel rays, as those which come from the sun are supposed to be brought to a focus.

Lecture XXXIII.

I. Of the senses in general.

There are certain parts of animals entirely insensible as the bones, the blood, the lymph, the fat: the nerves are the sensible part.

The eye is more easily excited, and more capable of delicate feeling than any other part because the optic nerve is most exposed by lying wholly on the surface.

Hearing, tasting, and smelling are less delicate than the eye, because they are less exposed. Hearing is produced by the tremulous motion communicated to the air by a body. The sensation of touching is effected by contact only. Smell is produced by particles flying off from a body. Taste by particles separated by contact.

The difference in the senses arises from some of the nerves being more exposed than others.

The sense of touching gives an idea only when we touch a body with the hand or some flexible part; for if the body be presented to the shoulder we conceive no idea of the figure of it.

The great advantage of the hand consists in its being flexible, and capable of conforming itself to the different surfaces of bodies.

The difference in the understanding of different animals arises from the different aptitude of the exterior parts to apply themselves to the surfaces of bodies. Animals which have hoofs have very imperfect ideas of things and are apt to be frighted, as horses &c.

II. Of Vision.

The eye consists of three coats and three humours. The coats are 1. The outer coat called the sclerotica part of which is called the cornea. 2. Without this coat is that called the choroides, which serves as it were for a lining for the other and joins with the iris. 3. The third coat is only a fine expansion of the optic nerve like net work and is called the retina, upon which the images of objects are painted. The humours are. 1. The aqueous humour. 2. The chrystalline. 3. The vitreous.—

Vision is effected by the rays of light which pass through the chrystalline lens and the humour of the eye, being brought to a focus in the retina, and there forming the image of the object.

If the back part of the eye be cut away and a piece of paper applied, the image of a candle placed before it will be formed inverted on the paper.

The image is formed upon the retina when the divergency is too great for the lens to bring them to a focus on the retina.

Vision is bright when a sufficient number of rays enter the eye: obscure when a sufficient number do not enter: distinct when the image is on the retina; and confused when the image is found beyond or below the retina.

The nearest limit of distinct vision to the naked eye is about 6 inches, but this differs with the eye. It may be lessened by making a pin hole through a piece of paper; for this will intercept the diverging rays, and only those will enter which can be brought to a focus on the retina.

The distance at which remote objects may be seen is about 3436 times the diameter.

If the eye be too convex, the rays are brought to a focus too soon unless the object be held very near the eye. They are called myopes. Such eyes can see small objects better than common eyes. If on the contrary the eye be too flat, the rays are not brought to a focus on the retina: this is the case with most old eyes which causes old people to hold the object at a distance, that the rays may enter the eyes less diverging and be brought to a focus on the retina.

Eyes which are too convex become better as they grow older, and may be remedied by using convex glasses, which prevents the rays from being brought to a focus too soon. Eyes which are too flat require the assistance of concave glasses that the rays may be made to converge more, and brought to a focus on the retina.

We judge of the magnitude of bodies by means of the optic angle.

The optic angle is the angle comprehended between the rays which flow from the extremities of the object, and cross in the pupil.

We judge of distance. 1. By the divergency of the rays when the object is near. 2. By the angle comprehended between the optic axis; but this also fails in great distances; because a considerable attraction in the position of the object will make but a little difference in the direction of the optic axis; in this case we must have recourse to the brightness, distinctness, and apparent magnitude of the object, and also to the intermediate objects which divide the distance into several small spaces of which we can judge better. All objects on the retina would appear equally distinct unless assisted by the touch.

That we never see the real object is shown by distorting the eye, when we appear to see two objects. The instance of the young man who was restored to sight at the age of 16 by the famous Chieselden proves it also. He had a favourite cat which he knew by feeling but when she was put before him after he received his sight he supposed her to be his head until he was convinced by touch.

The other ways by which we judge of distance are. 1. By the brightness. 2. By the visible or apparent magnitude. 3. By the interposition of objects.

The optic axis concurring at the object seen, the image in both eyes appears to be in the same place; and as we know that two objects cannot exist in the same place at once, we suppose there is but one. This may also in some measure be the effect of experience

Squinting arises from an inability to direct the axis of the eye to the same object: it may be remedied by accustoming ones-self to direct both axes to the same object or point.—

Lecture XXXIV.

Of Microscopes & Telescopes.

There are two kinds of microscopes, the simple & compound. The simple microscope is formed by one convex glass which causes the rays to converge and enables the eye to look at an object much nearer than it otherwise could.

The object must be placed at the focal distance of the parallel rays, that the rays may enter the eye parallel and be brought to a focus on the retina.

The object appears magnified because we are enabled to look at it nearer i.e. under a great angle: also the object appears more bright, because the eye receives the rays more divergent than it otherwise would do.–

To find the magnifying power of the glass, divide 6 inches by the focal distance of the glass.

Eye glasses may be either concave or convex. To determine the magnifying power, divide the focal distance of the object glass by the focal distance of the eye glass.

It is necessary to use an eye glass of a limited convexity, because the spherical surfaces do not accurately refract the rays of light to a focus; and also, on account of the different refraction of the different kinds of rays, they cannot be all collected to a point. The focal distance of the eye glass must be as the square root of the focal distance of the object glass.

The reflecting telescope was invented by Sir Isaac Newton, and improved by Herschel so as to magnify 6,000 times.–

To determine the magnifying power, multiply the focal distance of the great mirror by the distance of the small mirror from the image next the eye; and multiply the focal distance of the small mirror by that of the eye glass: divide the first product by the last, it will give the magnifying power.

As the rays of light suffer different degrees of refraction in passing obliquely through a prism or convex glass and are thereby separated into all the seven or primary colours: so they also suffer different degrees of refraction by passing through drops of falling rain, and then being reflected towards the eye from the sides of those drops which are farthest from the eye, and again refracted by passing out of those drops into the air in which refracted direction they come to the eye. They make all the colours appear to the eye in the form of a fine arch in the heavens, which is called the rain bow. There are always two rain bows seen together, the interior and the exterior; for the explanation of which see Ferguson 246 page.