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ANALYSIS

Of a COURSE of

LECTURES,

ON

MECHANICS, || HYDROSTATICS,
PNEUMATICS, || AND ASTRONOMY;

Read by

JAMES FERGUSON.

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J. F.

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ANALYSIS

ANALYSIS
OF A
COURSE of LECTURES.

LECTURE I.
On MECHANICS.

WHEN two bodies are ſuſpended upon any machine or engine, ſo as to act againſt one another, if the engine be put into motion, and the perpendicular aſcent of one body be to the perpendicular deſcent of the other in the inverſe ratio of their weights, they will balance or ſupport each other.

Upon this principle, the force, power, or advantage of any machine, whether ſimple or compound, is eaſily computed: for it is always as much as the velocity of the power applied to work the machine is greater than the velocity of the weight to be raiſed, or the reſiſtance to be overcome: proper allowance being made for friction.

The *machines* whereby power is gained, are called *mechanical powers*. They are ſix in number, *viz.* the *lever*, the *wheel and axle*, the *pulley*, or rather ſyſtem of pullies, the *inclined plane*, the *wedge*, and the *ſcrew.*—Of theſe, all ſorts of mechanical engines do conſiſt: and in treating of them, ſo as to ſettle their Theory, we conſider them as mathematically exact and perfect, and moving without friction.

A *lever* is a bar, turning upon a prop or center of motion; and is uſed either to raiſe weights, or to overcome reſiſtances.—There are three kinds of levers; and in each of them, the velocity of each point is directly as its diſtance from the prop.

A lever

A lever is ſaid to be of the firſt kind, when the prop is between the weight and the power.—Here, the power and weight balance each other, when the power is in proportion to the weight, as the diſtance of the weight from the prop is to the diſtance of the power from it. Of this ſort are our iron crows, ſciſſars, pincers, ſnuffers, and the like.

A lever is ſaid to be of the ſecond kind, when the weight is between the prop and the power.—Here, the power and weight balance each other, when the power is in proportion to the weight, as the diſtance of the weight (or reſiſtance) from the prop is to the diſtance of the power from it. Of this ſort are doors turning on hinges, rudders of ſhips, oars, and ſuch cutting knives as are fixed at the point.

A lever is ſaid to be of the third kind, when the power is between the weight and the prop. In this, the power and weight balance each other, when the power is in proportion to the weight, as the diſtance of the weight from the prop is to the diſtance of the power from it. Of this ſort are the bones of our legs and arms, and the wheels of clocks and watches.

The bended lever differs in nothing but its form from a lever of the firſt kind: its power is the ſame, and is applicable to that of a hammer drawing a nail.

In the *wheel and axle*, the velocity of the power is to the velocity of the weight, as the circumference of the wheel is to the circumference of the axle; and the advantage gained by this machine is directly in the ſame proportion: for the power and weight balance each other, when the power is in proportion to the weight, as the circumference of the axle is to the circumference of the wheel. This machine is the principal part in a common *crane*.

A *pulley*, that only turns on its axis, and does not riſe with the weight, ſerves only to change the direction of the power; for it gives no mechanical advantage thereto.

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When, besides the upper pullies which turn round in a fixed block, there is a block of pullies moving equally with the weight; the velocity of the weight is to the velocity of the power, as 1 is to twice the number of pullies in the moveable block: and the power and weight balance each other, when the power is in proportion to the weight, as 1 is to twice the number of pullies in the moveable block.

A weight raised, or a resistance moved, by an *inclined plane*, moves only through a space equal to the height or thickness of that plane, in the time that the power drives the plane through a space equal to its whole length. Hence, the velocity of the power is in proportion to the velocity of the weight, as the length of the plane is to its thickness or height; and the power and weight balance each other, when the power is proportioned to the weight, as the thickness of the plane is to its length.— All edge-tools which are chamfered only on one side are inclined planes, as far as the chamfer goes from the edge.

A *wedge*, in the common form, is like two inclined planes joined together at their bases; and the thickness or height of these planes make the back of the wedge, to which the power is applied in cleaving of wood.

When two equal resistances act perpendicularly against opposite sides of the wedge, and a power acts perpendicularly against the back of the wedge, the velocity of the power is in proportion to the velocity of the resistance, on each side, as the length of the wedge is to half the thickness of its back: and the power balances the resistance of the wood, when the power is in proportion to the resistance, as half the thickness of the back of the wedge is to its whole length, if the sharp edge goes to the bottom of the cleft in the wood. But when the wood splits before the wedge, as it generally does, the velocity of the refiftance on each fide is to the velocity of the power acting on the wedge, as half the thicknefs of the wedge is to the whole length of the cleft. And in this cafe, the power and refiftance balance each other, when the power is to the refiftance, as half the thicknefs of the wedge (when it is driven quite into the wood) is to the whole length of the cleft below the back of the wedge.

The *fcrew* may be confidered as if it were an inclined plane wrapt round a cylinder; hence, the power muft turn the cylinder quite round, in the time that the weight or refiftance moves through a fpace equal to the diftance between the fpirals or threads of the fcrew. Therefore, the velocity of the power is in proportion to the velocity of the weight or refiftance, as the circumference of a circle defcribed by the power, in one turn of the fcrew, is to the diftance between the fpirals of the fcrew: and the power and refiftance balance each other, when the former is to the latter, as the diftance between the fpirals is to the circumference of the circle defcribed by the power.—This machine, befides the advantage proper to itfelf, has generally the benefit of the wheel and axle, on account of the handle or lever by which it is turned.

As the fcrew includes the inclined plane, and two equally inclined planes make the wedge, we have all the mechanical powers combined together in a common *jack*, if it be turned by the fly: for then, we have alfo the lever, the wheel and axle, and the pullies.—If this machine be made ufe of for raifing a weight, by a power applied to the fly, the power will balance the weight, if it be in proportion to the weight, as the velocity of the weight is to the velocity of the fly. Now, confidering how faft the fly moves with refpect to the motion of the weight, it is evident that a crane, conftructed in the manner of a common jack, would

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be an engine of very great power. But then the time loſt would alſo be very great. For in all engines, the time loſt in working them is as the power gained by them. If machines could be made without friction, the leaſt degree of power added to that which balances the weight would be ſufficient to raiſe it.—In the lever, the friction is next to nothing: in the wheel and axle it is but ſmall: in the pullies it is very conſiderable; and in the inclined plane, wedge, and ſcrew, it is very great.

Pyrometers are machines for meaſuring the expanſion of metals by heat. They are made of various forms, which cannot be deſcribed here. By two levers of the third kind, moving an index by means of a thread round a pulley on the axis of the index, a pyrometer may be made in a very ſmall compaſs, which will ſhew the expanſion of metals to the 70,000dth part of an inch.

LECTURE II.

On MECHANICS.

THE *center of gravity* of a body is a point, round which all the parts of the body balance each other: and the body is moved by its own weight in the ſame manner that it would be, if its whole weight acted in that point. Therefore, the weight of a body will cauſe it to fall, unleſs its center of gravity be ſupported.

If a perpendicular, let fall from the center of gravity, falls within the baſe, or ground on which the body is placed, the body will ſtand: otherwiſe not.

A *cylinder* is ſupported on an inclined plane, by a power which is in proportion to the weight of the cylinder, as the height or thickneſs of the plane is to the length of the plane. If the power be leſs, the cylinder will run down the plane; if greater, it will be drawn up.—Hence, when the weight of a loaded *cart* or *waggon*, and the angle of a hill's height, are given; the power required to ſupport the load may be found. And if that power be encreaſed, ſo as to overcome the friction of the wheels on their axles, and the reſiſtance ariſing from the inactivity of matter, the load will be drawn up.

Thus ſuppoſing the ſide of the hill to be a ſmooth plane, and the angle of its height to be 7 degrees 10 minutes, the perpendicular height of the hill is, in that caſe, equal to the eighth part of the length of its ſide: and the power that ſupports the load thereon is equal to an eighth part of the weight of the load.

If the angle of height be 14 degrees 28 minutes, the height of the hill is equal to a fourth part of the length of its ſide: and a power equal to a fourth part of the load will ſupport it.

If the angle of height be 22 degrees 2 minutes, the height of the hill is equal to three eighth parts of the length of its ſide: and a power equal to three eighths of the load will ſupport it.

If the angle be 30 degrees 00 minutes, the height of the hill is equal to half the length of its ſide: and a power equal to half the weight of the load will ſupport it on the hill.

If the angle be 38 degrees 41 minutes, the height of the hill is equal to five eighth parts of the length of the ſide: and a power equal to the five eighths of the weight of the load will ſupport it.

If the angle be 48 degrees 35 minutes, the height of the hill is equal to three quarters of the length of its ſide: and a power equal to three quarters of the weight of the load will ſupport it.

If the angle of height be 61 degrees 3 minutes, the height of the hill is equal to ſeven eighth parts of the length of its ſide: and a power equal to ſeven eighth parts of the weight of the load will ſupport it.

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All theſe caſes are experimentally proved by the inclined plane; which ſhews, that the power or advantage of that plane is as its length to the height.

It is proved, by working models of two *waggons*, one of which has *broad* wheels and the other *narrow*, that broad wheels are juſt as eaſily drawn on hard ground as narrow ones; and eaſier on ſandy ground, becauſe they ſink not ſo deep into the earth.—It is alſo plain by experiment, that let the wheels be either broad or narrow, the waggon is much eaſier drawn on rough ground, when the heavieſt part of the load is put over the axle of the hind wheels, than when it is put over the axle of the fore ones.

In *water-mills*, the velocity of the float-boards of the wheel ought to be equal to a third part of the velocity of the water where it turns the wheel: and the train ſhould be ſuch, that the grinding-ſtone may make about 60 revolutions in a minute.

The number of rounds, or upright ſtaves in the trundle, ſhould be no aliquot part of the number of cogs in the wheel that turns the trundle: for then, each cog will fall upon a different round from what it did laſt before; and by that means they will all wear more equally, than if it took the ſame round in each revolution.

The *engine* by which the *piles* were driven at Weſtminſter-Bridge was ſo contrived, that whilſt the horſes that turned it went conſtantly round, a weight was drawn up by it to a great height, then let fall freely on the top of the pile, and was immediately followed by a pair of tongs which took hold of the weight and drew it up again. A large fly regulated the motion, and acted againſt the horſes, to keep them from falling forward when the weight dropt. The tongs were nearly counterpoiſed by another weight, whoſe line or rope wound round a ſpiral fuſee, ſo as to cauſe the tongs to fall with a moderate and uniform velocity.

LECTURE III.

On HYDROSTATICS.

FLUIDS preſs equally in all manner of directions, as is ſhewn by their motions in four glaſs tubes, open at each end; one tube being quite ſtraight, another bent directly upward at the lower end, a third bent ſidewiſe to a right angle, and the fourth bent obliquely. All theſe being put in water near to their tops, the water riſes in each of them to a level with the ſurface of that in which they are immerſed.

If a piece of lead, whoſe upper ſide is flat, be put into an empty veſſel; and a piece of wood, whoſe under ſide is flat, be put upon the lead, ſo as no water may get between; and the wood be held down till the veſſel be filled with water, the wood will remain upon the lead at bottom: for it is then kept down both by its own weight, and the weight of the water above it; the upward preſſure of the water being prevented, as none gets in between the lead and the wood.

If a wide tube, open at both ends, has a piece of lead held cloſe to its lower end, by a ſtring within the tube, ſo as no water can get between the lead and the tube; and then, if the whole be immerſed in water, till the depth of the lead below the ſurface of the water in the veſſel be almoſt twelve times the thickneſs of the lead, the ſtring may then be let go; for the lead will not fall away from the tube, becauſe the upward preſſure of the water is greater than the weight of the lead; and no water gets above it to preſs it down.—But if the tube and lead be raiſed, till the depreſſion of the lead below the ſurface of the water in the veſſel be any thing leſs than $11\frac{1}{3}$ times the thickneſs of the lead, it will then fall off: which ſhews, that lead is $11\frac{1}{3}$ times as heavy as its bulk of water.

If quickſilver be poured into a wide tube, which is cloſe at bottom, to the height of an inch or two; and one end of a ſmall tube, which is open at both ends, be immerſed in the quickſilver; if then the large tube be filled to any height with water round the ſmall one, the weight of the water on the quickſilver will preſs it upward in the ſmall tube, till its height in that tube be a fourteenth part of the height of the water around the tube. This ſhews that quickſilver is fourteen times as heavy as water.

If a tube open at both ends has a bladder tied over one end, ſo as the bladder may be flaccid, and then ſome water be poured into the tube, it will preſs the bladder downward, and make it concave below the tube. But if that end be immerſed in a veſſel of water, till the ſurface of the water within the tube be even with the ſurface of the water in the veſſel without it, the bladder will then be flattiſh, as if it were not preſſed at all, becauſe it is equally preſſed on both ſides.—If it be plunged deeper, it will be preſt upward, ſo as to convex within the tube: if it be raiſed higher, it will be more preſt downward than upward, and be concave below the tube. And this will hold equally, whatever the ſize of the veſſel be, in which the tube is immerſed: which ſhews, that the preſſure of fluids is in proportion to their perpendicular height, without any regard to their quantity.

If a ſmall tube be joined to a very large one, and the whole be bent in the middle, ſo as the two parts may be either parallel, or make any angle; water may be poured into either tube, and it will riſe juſt as high in the other, and ſettle with ſurfaces parallel to the horizon, when you leave off pouring; even though one tube ſhould contain a thouſand or ten thouſand times as much as the other does.—This alſo ſhews, that fluids preſs in proportion to their perpendicular heights, without any regard to their quantities; and that water in pipes will aſcend to the level of the ſpring, from whence it came.

If an empty phial, that is made heavy enough to ſink in water, be corked and ſuſpended at one end of a balance, and then immerſed in water, and counterpoiſed by weights in a ſcale hung to the other end of the beam; upon pulling out the cork, and ſo letting water get in to fill the phial, it will immediately deſcend, and will then require as much weight put into the ſcale to counterbalance it again, as will weigh all the water in it, up to the neck, when taken out and weighed againſt this additional weight: which ſhews, that fluids weigh juſt as much in their own element as out of it.

If a ſmall tube about two feet long, and open at both ends, has one end bent to a right angle, and the open neck of a large bladder be tied round that end; if then the bladder be put into a box, and have a board laid upon it with twenty-five or thirty pound weight of lead upon the board; and then the tube be held upright, and water be poured into it, the water will run into the bladder, and raiſe all the weight: and by the time that the water ſtands about eighteen or twenty inches high in the tube, it will ſupport the weight; though the bore of the tube ſhould be ſo ſmall, as not to hold an ounce of water.

If a glaſs, with a piece of light wood in it, be filled up to the brim with water, and then weighed in a balance, with the wood floating in the water; if then the wood be taken out, and the glaſs filled up again to the brim with water, it will be juſt as heavy as when the wood was in it: which proves, that a quantity of water equal in bulk to the immerſed part of the wood is equal in weight to the whole of the wood; and conſequently, that the quantity of water diſplaced by a ſhip is equal to the weight of the ſhip and her whole cargo.

The preſſure of a fluid, upon the bottoms of all veſſels whatever, is proportional to their baſes and perpendicular heights, without any regard to the quantities they contain.—This is ſhewn by two veſſels of equal heights and baſes, but of very different capacities, their bottoms being held up by equal forces; for, at whatever height the water is in one veſſel when it preſſes off the bottom, it does the like when poured in to the ſame height in the other.

A *ſyphon* will not run, unleſs the perpendicular height of the column of fluid in the outer leg be greater than the perpendicular height of the column in the inner leg above the ſurface of the fluid in the veſſel in which that leg is partly immerſed.

By the *Tantalus cup*, and *Fountain at command*, the cauſe of intermitting ſprings is explained.

LECTURE IV.

On SPECIFIC GRAVITIES, *and* HYDRAULIC ENGINES.

A Body heavier than its bulk of a fluid will ſink therein; if lighter, it will ſwim: if of equal weight, it will reſt any where between the top and bottom of the fluid.

If a ſolid body, heavier than its bulk of a fluid, be immerſed and ſuſpended therein, it will loſe as much of its weight as its bulk of the fluid weighs: but the weight loſt by the ſolid is gained by the fluid, as is proved by experiment. Hence, all equal bodies, immerſed and ſuſpended in a fluid, loſe equal weights therein: and unequal bodies loſe weights proportional to their bulks.

If the weight of a body in air be divided by what it loſes in a fluid, the quotient will ſhew how much heavier it is than its bulk of that fluid; or its ſpecific gravity.

By this trial, pure gold is found to be 19.637 times as heavy as its bulk of water: Guinea gold

17.793 times as heavy: quickſilver 14.000 times lead 11.325 times: ſtandard ſilver 10.535: coppe 9.000: plate braſs 8.000: ſteel 7.852: iron 7.645 and block tin 7.321 :——A cubic foot of commo water weighs 1000 avoirdupoiſe ounces; and if th decimal point be taken away from the above num bers, and they reckoned to be whole, they will ſhew how many ounces avoirdupoiſe are contained in a cubic foot of each of the above bodies.—Thus, a cubic foot of pure gold weighs 19637 ounces; a cubic foot of Guinea gold 17793; a cubic foot o quickſilver 14000; and ſo on.

A cubic inch of braſs loſes 253$\frac{1}{3}$ grains of it aerial weight in water; in proof ſpirits it loſes 23 grains. Hence, a cubic inch of water weighs 253 grains, and a cubic inch of proof ſpirits 235.

The ſpecific gravities of pure ſpirits, proof ſpirits and water, are as 840, 923, and 1000.

In *a common pump*, as the piſton is raiſed, abov what is called the ſucking valve, the water riſe by the preſſure of the atmoſphere to the height o 33 feet, and no higher. Therefore, the bucke muſt go down to within 33 feet of the ſurface of th water in the well; otherwiſe, the water will neve get above the bucket, and the pump will not work

This ſhews, that a column of water 33 feet high is juſt as heavy as a column of air of the ſam thickneſs with that of the water, and reaching from the earth's ſurface to the top of the atmoſphere.

But at any diſtance leſs than 33 feet from th ſurface of the well, the water will riſe above th bucket; and may then be lifted to any height whatever, by applying a ſufficient degree of power to the handle.

In *a forcing pump*, the water riſes above the ſucking valve, by the preſſure of the atmoſphere, as in th common pump. But inſtead of a bucket, there i a ſolid plunger that fits the pump-bore, ſo as neithe

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water nor air can get between. As the plunger is raiſed, it lifts up all the air above it, and the atmoſphere forceth the water up into the pump-barrel, through the ſucking valve, which being raiſed by the upward preſſure of the water, falls down by its own weight when the plunger is raiſed as far as it can go by means of the handle; for then, the water being at reſt below the plunger, gives the valve liberty to fall; and ſo the valve hinders the water from being puſhed back the ſame way again by the deſcending plunger: but the deſcent forceth the water through another pipe, which opens into the pump-barrel above the ſucking valve; and may be forced to any given height in that pipe, or in a jet from it, according to the degree of power applied to the handle. An air-veſſel is fixed to this pipe, by means of which, as the air is condenſed within it, the water flows out in a regular continued ſtream.—The common engine for extinguiſhing fire conſiſts of two forcing pumps, with their air-veſſels.

On this principle, engines are made for raiſing water above the level of rivers or ſprings, to gentlemen's ſeats; and are ſometimes worked by water, ſometimes by horſes. If ſuch an engine has a triple crank for working three pumps, all of them throwing the water into one common conduit pipe, there will be no occaſion for an air-veſſel; becauſe there will always be one or other of the plungers going downward, which will force the water out in a regular ſtream.

LECTURE V.

On PNEUMATICS.

THE ſtructure of the principal parts of the *air-pump* is ſo much like that of the common water-pump, that whoever underſtands the one, will be at no loſs to underſtand the other. The chief uſe of this engine is to exhauſt the air out of glaſs veſſels, generally called *receivers*.

If a ſmall receiver, open at both ends, be placed over the hole in the pump plate, and a perſon claps the palm of his hand on the top of the receiver, whilſt another perſon exhauſts the air out of the receiver, his hand will be held down ſo faſt by the preſſure of the atmoſphere, that he cannot pull it off until the air be let into the receiver again.

If a guinea and the down of a feather be hung within the top of a tall receiver, and let fall after the air is exhauſted out of it, they will both fall at the ſame inſtant on the pump plate whereon the receiver ſtands.

If a wet bladder be tied over the top of an open receiver, then ſet to dry, ſo as to be tight like a drum; and the receiver be then put upon the pump plate, and the air exhauſted out of it, the bladder will be broke by the weight of the atmoſphere.

If the neck of a hollow glaſs bubble be immerſed in a phial of water, and covered with a cloſe receiver, and then the air be exhauſted out of it; upon letting the air in again, its preſſure on the water in the phial will force the water up into the bubble, ſo as almoſt to fill it.

If a bell be covered with a cloſe receiver, and the air be exhauſted out of it, the ſtriking of the clapper againſt the ſides of the bell will not be heard.

If a pump be placed in water, under a receiver, and the air be exhauſted, no water can be raiſed by working the piſton, until the air be let in again: which ſhews, that the water riſes by the preſſure of the air; and not by any ſuch thing as ſuction in the pump.

If a ſmall receiver be placed on the pump plate, at ſome diſtance from the hole, and covered with a

large

large receiver over the hole; and then, if the air be exhausted out of both receivers, the small one will continue loose on the plate, and the large one will be prest down upon it. But, upon letting the air into the big receiver, it will be released, and the small one will be prest down: which shews, that the receivers are held down by pressure, and not by suction.

If a vessel be exhausted of air, and then balanced in a pair of scales; upon letting the air into it again, it will preponderate, and be found to weigh heavier, by about 16 grains, for every quart it holds.

If a hole be made in the bottom of a cup, and have a bit of dry hasel or willow branch fixed into it, and the other end of the branch be fixed into a hole in the top of a receiver; if quicksilver be poured into the cup, and the air be exhausted out of the receiver below it, the quicksilver will be forced through the pores of the branch, by the weight of the incumbent air; and will fall, like a shower, into the receiver.

If a pipe be fixed into a plate which covers the open end of a tall receiver, and the air be exhausted; if then the lower end of the pipe be immersed into a bason of water, the pressure of the air will force the water upward, so as to make a fountain in the exhausted receiver.

If the air be exhausted out of two hemispherical brass cups, joined together only by a piece of wet leather put between them; if the diameter of each cup be $5\frac{1}{2}$ inches, it will require a force equal to 360 pounds to separate them; so strongly are they held together by the pressure of the outward air.

If a tube about 31 or 32 inches long, and open at one end, be filled with quicksilver, and the open end be immersed in a jar in which there is some quicksilver, the quicksilver will sink in the tube to the height at which it then ſtands in the barometer. If this jar and tube be placed on the pump plate, and covered with a tall receiver, cloſe at top, and then the air be exhauſted out of the receiver, all the quickſilver will deſcend out of the tube into the jar: but, upon admitting the air again into the receiver, it will preſs on the quickſilver in the jar ſo, as to drive it up into the tube, and ſupport it at the ſame height therein as it ſtands in the barometer: which ſhews, that the quickſilver in the barometer is kept up ſolely by the weight of the air.

LECTURE VI.

On PNEUMATICS.

IF a leaden weight of three or four pounds be fixed to the end of a ſyringe, and the piſton be drawn up, the lead and ſyringe will be forcibly puſhed up on the piſton, by the upward preſſure of the air.

If a large cork be exactly counterbalanced in air by a piece of lead, and then covered with a receiver; upon exhauſting the air, the cork will preponderate, and ſhew itſelf to be heavier than the lead.

If a candle be ſet on the pump plate, and covered with a tall receiver that holds a gallon, the candle will burn for one minute and no longer: which ſhews, that a gallon of freſh air is requiſite every minute to feed the flame of a candle. When the flame goes out, the ſmoke will continue to aſcend in the receiver; but, on exhauſting the air out of the receiver, the ſmoke will fall down to the bottom of it on the pump plate. This ſhews, that ſmoke is not devoid of weight, and that it aſcends in air, only becauſe it is lighter than air; as wood aſcends in water for the like reaſon.

If a little air be tied up in a bladder, and the bladder be covered with a cloſe receiver, upon exhauſting the air out of the receiver, the air confined in the bladder will expand ſo, as to make the bladder appear full blown: but, upon admitting air again into the receiver, the bladder will be preſt into its former ſhrivelled ſtate.

If the ſame bladder be put into a box, and have 16 or 20 pound weight of lead put upon it, and then covered with a receiver; upon exhauſting the air out of the receiver, the air confined in the bladder will raiſe up the leaden weights by the force of its ſpring.

Moſt ſorts of animals will die in the greateſt agonies in an exhauſted receiver.

If a tube, open at both ends, has one end immerſed into a jar about a third part full of quickſilver, and the tube be cemented (or ſcrewed) into the jar, to confine the air therein that lies above the quickſilver, and the tube and jar be covered with a tall receiver; on exhauſting the receiver, the air will come out of the tube by means of its ſpring, and the ſpring of the air which is confined in the jar will force the quickſilver up into the tube, as high as it was raiſed in a former experiment by the weight of the air: which proves, that the ſpring of the air is equal to its preſſure or weight.

If a tall receiver be exhauſted of air, and joined by a pipe to a veſſel about half full of water, ſo as to be quite air-tight, the ſpring of the air that lies above the water in the veſſel will force the water up into the receiver, and make a fountain therein.

If a ſhrivelled apple be put under a receiver, and the receiver be exhauſted of air; the air confined in the apple will plump it out, and make it look quite freſh: but on letting the air into the receiver again, its weight will reduce the apple to its former ſhrivelled ſtate.

If a fresh apple be pricked all over with a bodkin, and put under a receiver; upon exhausting the air out of the receiver, the air in the apple will force the juice out through the holes made by the bodkin; and make the apple look as if it were roasting by a fire.

If a little of the shell be cut off from the smallest end of a fresh egg, and the egg be put under a receiver; on exhausting the receiver, the bubble of air confined in the biggest end, between the film and shell, will expand itself so by the force of its spring, as to drive out the contents of the egg into the exhausted receiver.

If a glass of warm beer be put under a receiver, and the receiver be exhausted, the beer will shew all the appearance of boiling, as the air comes out of it by the force of its spring.

If about a cubic inch of dry wainscot be put into a glass of warm water, and covered with a receiver; on exhausting the air out of the receiver, the water will seem to boil; and a long time after it has done bubbling, the air will continue to come out of the wood in large and innumerable bubbles, which striking against the sides of the glass, and rebounding against the wood, will cause it to dance to and from in the water.

If a receiver be exhausted of air, and then the air be let into it through the flame of a candle, held to the end of a pipe which opens into the receiver through a brass cover, the receiver will be filled with burnt air. If then the cover be taken off, and an animal be put into the receiver, it will die: or if a lighted candle be put into the receiver, it will go out immediately.

LECTURE VII.

On the USE *of the* GLOBES.

WHEN the earth's ſhadow falls upon the moon, it is bounded by a circular line, whatever ſide of the earth be then turned toward the moon.—This proves the earth to be a ſpherical body, and not an extended plane. Its circumference is found (by meaſuring the length of ſome degrees on its ſurface) to be 25,038½ Engliſh miles; and conſequently its diameter is 7970.

All terreſtrial bodies are attracted towards the earth's center; and, therefore, no body can fall from any part of its ſurface any other way than toward its center.—Hence, people ſtands equally firm on all ſides of the earth.

The four principal continents are, Europe, Aſia, Africa, and America.

The principal Oceans are, the Northern Ocean, the Atlantic Ocean, the Ethiopic Ocean, the Indian Ocean, the Pacific Ocean, the Southern Ocean.

According to meaſurement from the beſt maps, the ſeas and unknown parts contain 160,566,276 ſquare miles; the inhabited parts 38,990,569; Europe 4,456,065; Aſia 10,768,823; Africa 9,654,807; America 14,110,874. In all, 199,556,845; which is the number of ſqure miles on the whole ſurface of our globe.

When a ſpherical ball has the different countries and kingdoms delineated upon it, and the rivers and towns therein properly marked, it is a repreſentation of the earth: for the hills take off no more in compariſon from the roundneſs of the earth, than grains of duſt do from the roundneſs of a common globe.

When a hollow ſpherical ball of glaſs has the ſtars properly marked on its inſide, with the ſun, moon, and

and planets, it is a reprefentation of the vifible heavens, to an eye fuppofed to be placed in its center.—But becaufe it would be impoffible to have thefe in a complete hollow ball of glafs, unlefs it were made up of two hemifpheres joined together, the ftars are laid down on the furface of an opake globe. The fun and planets are continually changing their places, and therefore they cannot be marked any other way than by a pencil or chalk occafionally.

The chief problems which may be folved by a terreftrial globe, properly fitted up, are as follow.

1. To find the latitude and longitude of any given place.

2. The latitude and longitude being given, to find the place.

3. To find the difference of latitude, or difference of longitude, between any two given places.

4. A place being given, to find all thofe places which have the fame latitude or longitude with it.

5. To find the *antæci*, *periæci*, and *antipodes* of any given place.

6. To find the diftance between any two given places.

7. A place being given, and its true diftance from any other place, to find all the other places which are at the fame diftance from the given place.

8. The hour of the day at any place being given, to find all thofe places where it is noon at that time.

9. The hour at any place being given, to find what o'clock it then is at any other place.

10. To find the fun's place in the ecliptic, and his declination.

11. The day of the month being given, to find all thofe places over which the fun will pafs vertically on that day.

12. A place being given in the torrid zone, to find thoſe two days of the year on which the ſun ſhall be vertical to that place.

13. To find all thoſe places of the north frigid zone where the ſun begins to ſhine conſtantly without ſetting on any given day, from the 21ſt of March to the 23d of September.

14. To find to what place the ſun is vertical at any given time.

15. The day and hour at any place being given, to find all thoſe places where the ſun is then riſing, or ſetting, or on the meridian: conſequently, all thoſe places which are enlightened at that time, and thoſe which are in the dark.

16. The day and hour of a lunar eclipſe being given, to find all thoſe places at which it will be viſible.

17. To rectify the globe for the latitude, zenith, and ſun's place.

18. The latitude of any place not exceeding 66½ degrees being given, to find the time of ſun-riſing and ſun-ſetting at that place.

19. The latitude of the place, and the day of the month, being given; to find when the morning twilight begins, and evening twilight ends.

20. To find on what day of the year the ſun begins to ſhine conſtantly without ſetting, at any place of the north frigid zone: and how long he continues to do ſo.

21. To find in what latitude the ſun ſhines conſtantly, without ſetting, for any length of time leſs than 182 of our days and nights.

22. To find on what point of the compaſs the ſun riſes, or ſets, in any given latitude leſs than 66½ degrees.

23. The latitude, the ſun's place, and his altitude, being given; to find the hour of the day, and the ſun's azimuth.

24. The latitude, the ſun's place, and his azimuth, being given; to find the hour of the day, and the ſun's altitude.

25. The latitude, the ſun's place, and the hour of the day, being given; to find the ſun's altitude, and his azimuth.

26. The latitude, the ſun's place, and his altitude, being given; to find the variation of the compaſs.

27. The latitude, the ſun's altitude, and his azimuth, being given; to find his place in the ecliptic, the day of the month, and the hour of the day: though they had all been loſt.

28. To find the length of the longeſt day, at any given place.

29. The length of the longeſt day, at any place being given; to find in what climate that place is.

30. To find in what latitude the longeſt day is of any given length leſs than 24 hours.

31. The latitude, and day of the month, being given; to find the hour of the day when the ſun ſhines.

32. To explain the equation of time.

33. To explain the phenomena of the harveſt-moon.

34. To explain the principles of dialing, and to conſtruct a ſun-dial on any plane, for any given latitude.

The chief problems which may be ſolved by the celeſtial globe are theſe that follow.

1. To find the right aſcenſion and declination of the ſun, or of any ſtar.

2. To find the latitude and longitude of any ſtar.

3. To repreſent the face of the heavens at any hour of the night.

4. To find the time, on any given day, when any ſtar will riſe, or be on the meridian, or ſet.

5. To

5. To find at what time of the year a given ſtar will riſe, or be upon the meridian, or ſet, at any given hour.

6. Divers ways of finding the hour of the night by the ſtars.

7. To find the place of the moon, or of any planet, on the globe; and the time of its riſing, or ſouthing, or ſetting.

8. To explain the preceſſion of the equinoxes.

N. B. All problems relating to the ſun may be ſolved either by the celeſtial or terreſtrial globe. The method of ſolving them would enlarge this treatiſe much beyond the intended bulk: but it is to be found in Mr. *Harris*'s book on the uſe of the Globes, ſold by Mr. *Cole* at the *Orrery* in Fleet-ſtreet; or in my book of Lectures, ſold by Mr. *Millar*, Bookſeller in the Strand.

LECTURE VIII.

On the CENTRAL FORCES, *and doctrine of the* TIDES.

MATTER, being inert, can neither move nor ſtop of itſelf, as is ſhewn by a ball on the *whirling table*; which neither begins to move when the table moves, nor ſtops when the motion of the table is ſtopped.—Conſequently, all motion is in its own nature perpetual. And yet, no perpetual motion can be made by art, becauſe we can neither annihilate friction, nor quite take off the reſiſtance of any medium.

Motion is rectilineal, when only one force or power acts upon the moving body. Therefore, when we ſee a body move in a curve of any kind whatever, we muſt conclude it is acted upon by two powers at leaſt.

All bodies moving in orbits, have a tendency to fly off from their orbits, and move in right lines:

 there-

therefore, to keep them in their orbits, ſome active power muſt be conſtantly drawing them, or impelling them, toward the center of their orbits: as is evident by a pebble whirled round one's hand in a ſling.

The planets are retained in their orbits by the power of gravity, and they are moved in their orbits by a projectile force impreſſed upon them at the beginning.

If the power of gravity alone acted on the planets, it would bring them down to the ſun.—If the projectile force acted alone on the planets, it would carry them off in ſtraight lines, which would be tangents to their orbits.

The ſun and planets mutually attract each other, in proportion to their quantities of matter.—The ſun's attraction is that which cauſes or conſtitutes the gravitation of the planets.

The center of gravity of any two revolving bodies is a point, round which they are in *æquilibrio*: its diſtance from their centers is inverſly as their quantities of matter.

When one body moves round another, both of them muſt move round their common center of gravity, as is plainly proved by experiment. Hence, the largeſt body in the ſolar ſyſtem could not remain immoveable, if any other body moved round it.

The quantity of matter in the ſun is much greater than in all the planets put together. Therefore, the common center of gravity between the ſun and planets is much nearer to the ſun than to any planet in the ſyſtem.

The common center of gravity between the ſun and all the planets is at reſt: but the common center of gravity between any planet and its ſatellite is moveable, and deſcribes the orbit in which the planet itſelf would move if it had no ſatellite.

The common center of gravity between the earth and moon is 6000 miles from the earth's center.—As the earth and moon move round their common center of gravity every month, the earth's center describes a circle of 12000 miles diameter in that time: and consequently, the earth is 12000 miles nearer the sun at the time of full moon, than at the time of new moon.

All parts of the earth have a tendency to fly off, in proportion to their distance from this common center of gravity: therefore the side of the earth which is at any time turned away from the moon has a greater centrifugal force, or tendency to fly off, than the earth's center has: and the earth's center has a greater centrifugal force, than that side of the earth which is turned towards the moon.

At the earth's center, the moon's attraction balances the centrifugal force: consequently, her attraction on the side next her is stronger than the centrifugal force of that side; and weaker than the centrifugal force of the side farthest from her. As the moon's attraction on the side of the earth next to her is greater than the centrifugal force of that side, her attraction causeth the tide to rise on that side.

As the centrifugal force of the side of the earth farthest from the moon is greater than the moon's attraction, the centrifugal force causeth the tide to rise on that side.

The tides rise equally high, or nearly so, at the same time, on both sides of the earth; because the centrifugal force of the side that is farthest from the moon overbalances her attraction very nearly as much, as her attraction on the side next her overbalances the centrifugal force of that side.

A double velocity, in the same orbit, balances a quadruple power of attraction at the center of that orbit, as is manifest by experiment.—Therefore, if the velocity of any planet were twice as great as it now is, the ſun's attraction would need to be four times as great, in order to retain the planet in its orbit.

The ſquares of the planets periods round the ſun are found by obſervation to be as the cubes of their diſtances from the ſun.—If this be repreſented on the whirling table, it appears, that the powers at the center requiſite to keep the planets in their orbits, are inverſly as the ſquares of their diſtances from the center of their orbits: which proves, that the ſun's attraction diminiſhes in proportion as the ſquares of the diſtances from him increaſe: that is, at a double diſtance, his attraction is four times leſs; at a triple diſtance, nine times leſs; at a quadruple diſtance, ſixteen times leſs; and ſo on.

The motions of the comets prove the *Carteſian* doctrine of vertexes to be abſurd. This is alſo proved by an experiment on the whirling table, made by mercury and water in one tube, and water and cork in another.

The earth is of a ſpheroidal figure, as is proved by the French obſervations; its equatoreal diameter being longer than its axis.—This demonſtrates that the earth turns on its axis: for, if it did not, the water would leave the equatoreal regions, and overflow the polar.—The whirling ſphere proves, that this figure of the earth ariſes from its motion on its axis.

LECTURE IX.

On ASTRONOMY.

NO ſcience is comparable to this, in giving us noble ideas of the Deity and his works; and drawing us near to him. The earth is at leaſt 160 millions of miles nearer ſome of the ſtars at one time of the year than another: and yet, the apparent magnitudes of theſe ſtars, and their angular

diſtances

diſtances from each other, is ſtill the ſame: which proves, that the diſtance of the ſtars from us is exceeding great.

At the diſtance of any ſtar, all the planets in our ſyſtem would diſappear: and the ſun would appear no bigger than a common ſtar does to us. Conſequently, each ſtar may be a ſun to a ſyſtem of planetary worlds, which our beſt teleſcopes cannot poſſibly diſcover.

The ſtars are vaſtly too remote from the ſun, to be enlightened by it, ſo as to reflect light enough to make them viſible. Hence it is plain, that they ſhine by their own native and unborrowed luſtre.

Thoſe of the firſt magnitude cannot be leſs than the ſun; otherwiſe they could not appear ſo large to us as they do.—Since they are ſo large, and ſhine by their own light, they are ſuns.

It is probable that all the reſt are as large, and only appear to be of different magnitudes, by reaſon of their different diſtances.

The number of ſyſtems which would ſtand around our ſolar ſyſtem, and next to it, is much leſs than the number of thoſe which might ſtand next around them.—And ſo on to infinity. But the ſtars of the firſt magnitude are much fewer in number than thoſe of the ſecond: thoſe of the ſecond much fewer than thoſe of the third: and ſo on.

This circumſtance makes it highly probable, that the ſtars of the firſt magnitude are ſuns to thoſe ſyſtems of planets next around our ſyſtem: thoſe of the ſecond magnitude, ſuns to thoſe ſyſtems next beyond our neighbouring ſyſtems: and ſo on, to the ſtars of the ſixth magnitude, which are the ſmalleſt that common eyes can perceive.

But by means of the teleſcope, thouſands of ſtars are diſcovered, which are quite inviſible to the bare eye. Thoſe are certainly of no manner of uſe to us; but we cannot therefore conclude, that they are ufelefs ; and confequently we infer, that they are funs to particular fyftems of worlds.

Our earth, if feen from the fun, would appear no bigger than a point ; as is evident from the fmallnefs of the fun's parallax.—It is a planet only of the third magnitude, for it is much lefs than *Saturn*, and *Saturn* is confiderably lefs than *Jupiter*.

The folar fyftem confifts of the fun, fix primary planets, ten fecondary planets or moons, and the comets.

The fix primary planets are *Mercury*, *Venus*, the *Earth*, *Mars*, *Jupiter*, and *Saturn*.—The *Earth* has one moon, *Jupiter* has four, and *Saturn* five.

All the planets move round the fun from weft, by fouth, to eaft ; in orbits which are nearly circular, and but little inclined to each other.—The comets move in all forts of directions, in orbits which are very long ellipfes, much inclined to one another, and to the orbits of all the planets. The tails of the comets are only thin vapours : for, if they were flame, no ftar could be feen through them.

The time in which any planet goes round the fun, is the length of its year ; and the time in which it turns round its axis, is the length of its day and night taken together.

Mercury goes round the fun in 87 days 23 hours : its diameter is 2600 Englifh miles, its diftance from the fun is 32,000,000 of miles, and its hourly motion in its orbit is 95,000 miles. The time of its diurnal rotation, or length of its days and nights, is unknown.

Venus goes round the fun in 224 days 17 hours : its diameter is 7900 miles, its diftance from the fun is 59,000,000 of miles, its hourly motion in its orbit is 69,000 miles, and it turns round its axis in 24 days 8 hours of our time.

The *Earth* goes round the fun in 365 days 5 hours 49 minutes : its diameter is 7970 miles, its diftance diſtance from the ſun is 81,000,000 of miles, its hourly motion in its orbit is 58,000 miles, and it turns round its axis in 24 hours.

The *Moon* goes round the earth, from change to change, in 29 days 12 hours 44 minutes; and turns round her axis in the ſame time. Her different phaſes prove that ſhe ſhines by reflecting the light of the ſun, and not by any light of her own. Her diameter is 2170 miles, and her diſtance from the earth is 240,000. In reſpect of the earth ſhe moves 2290 miles each hour in her orbit.

Mars goes round the ſun in 686 days 23 hours: its diameter is 4444 miles, its diſtance from the ſun is 123,000,000 of miles, its hourly motion in its orbit is 47,000 miles, and it turns round its axis in 24 hours 40 minutes.

Jupiter goes round the ſun in 4332 days 12 hours: its diameter is 81,000 miles, its diſtance from the ſun is 424,000,000 of miles, its hourly motion in its orbit is 25,000 miles, and it turns round its axis in 9 hours 56 minutes.

This planet has four moons moving round it, at different diſtances. Its firſt or neareſt moon goes round it in 1 day 18 hours 36 minutes, the ſecond in 3 days 13 hours 15 minutes, the third in 7 days 3 hours 59 minutes, and the fourth in 16 days 18 hours 30 minutes.

Saturn goes round the ſun in 10,759 days 7 hours: its diameter is 67,000 miles, its diſtance from the ſun is 777,000,000 of miles, and its hourly motion in its orbit is 18,000 miles. The time of its rotation on its axis is unknown.

This planet has five moons, the neareſt of which goes round it in 1 day 21 hours 19 minutes, the ſecond in 2 days 17 hours 40 minutes, the third in 4 days 12 hours 25 minutes, the fourth in 15 days 22 hours 41 minutes, and the fifth in 79 days 7 hours 48 minutes.

If a body, projected from the ſun, ſhould continue to fly at the rate of 480 miles every hour (which is about the ſwiftneſs of a cannon-ball) it would reach the orbit of Mercury in 7 years 221 days; of Venus in 14 years 8 days; of the Earth in 19 years 91 days; of Mars in 29 years 85 days; of Jupiter in 100 years 280 days; of Saturn in 184 years 240 days; and to the neareſt of the ſtars in about 8 millions of years.

The ſun's light diminiſhes in proportion as the ſquares of the diſtances from him increaſe.—Mercury is ſeven times as much enlightened as the Earth is: Venus twice as much; Mars has little more than a fourth part of ſo much light as the Earth has: Jupiter has only a twenty-eighth part, and Saturn a ninetieth part.

The ſun's diameter is 763,000 miles. If we ſuppoſe it to be divided into 10,000 equal parts, Mercury's diameter will contain $34\frac{1}{13}$ of ſuch parts; Venus's diameter $103\frac{4}{7}$; the Earth's $104\frac{3}{7}$; the Moon's $28\frac{1}{2}$, Mars's $58\frac{1}{6}$; Jupiter's $1061\frac{2}{3}$, and Saturn's $878\frac{1}{9}$.

Now, let us ſuppoſe that an *Orrery* is intended to be made, in which the ſun and planets ſhall be repreſented in their proportional magnitudes, and the planets placed at their proper diſtances from the ſun, in proportion to their magnitudes; as in the heavens: the ſun's diameter in the *Orrery* being 12 inches.

In this caſe, the diameter of Mercury would be $\frac{42}{1000}$ parts of an inch; the diameter of Venus $\frac{124}{1000}$ parts; the diameter of the Earth $\frac{125}{1000}$ parts (which is equal to the eighth part) of an inch; the Moon's diameter $\frac{34}{1000}$ parts; Mars's diameter $\frac{70}{1000}$ parts of an inch; Jupiter's diameter one inch and $\frac{274}{1000}$ parts; and Saturn's diameter, excluſive of his ring, one inch and $\frac{54}{1000}$ parts.

Then,

Then, the true proportional diſtances of theſe planets from the ſun would be as follows: Mercury's diſtance 43 feet 1 inch; Venus's diſtance 77 feet 2 inches; the Earth's diſtance 105 feet 10 inches; the Moon's diſtance from the Earth $3\frac{8}{10}$ inches; Mars's diſtance from the ſun 161 feet 5 inches; Jupiter's diſtance 555 feet 9 inches; and Saturn's diſtance 1018 feet 7 inches, or 339 yards 1 foot 7 inches.—So that the circumference of Saturn's orbit would be 2130 yards; or a mile and almoſt a quarter.

Conſequently, there is no ſuch thing as having the ſun and planets in their relative magnitudes, and at their proportional diſtances, in an *Orrery*; even though the earth ſhould be no more than the eighth part of an inch in diameter.

LECTURE X.

On ASTRONOMY.

THE axis of any planet is a phyſical line, round which the planet turns: and the extremities of that line are its poles.

The earth's motion on its axis is the cauſe of day and night: for its turning round every 24 hours produces the ſame effect, as if the ſun moved round it in that time.

The earth's axis inclines $23\frac{1}{2}$ degrees from a perpendicular to the ecliptic, or orbit in which the earth moves round the ſun. Therefore, the earth's poles can never incline more than $23\frac{1}{2}$ degrees toward or from the ſun.

The obliquity of the earth's axis, and its conſtant paralleliſm during its annual courſe round the ſun, are the cauſes of the different ſeaſons, and different lengths of days and nights.

The north pole of the earth's axis inclines more or leſs toward the ſun, from the vernal exquinox to the autumnal; and more or less from the sun, from the autumnal equinox to the vernal.—In the former case, it is the summer half year in the northern hemisphere of the earth; in the latter case, the winter half year: and the contrary in the southern hemisphere of the earth. For, when the north pole inclines toward the sun, the south pole declines from him, and *vice versa*.

In the northern hemisphere, the vernal equinox (or equal day and night in the spring) is on the 20th of March; and the autumnal equinox (or equal day and night in autumn) is on the 23d of September. In the southern hemisphere, the contrary.

The earth goes round the sun once a year in the plane of the ecliptic: and therefore, as seen from the earth, the sun appears to go round the ecliptic in the same time. For, in whatever place of the ecliptic the earth is, at any time, as seen from the sun, the sun, as seen from the earth, will seem to be in the opposite part of the ecliptic.

The equator is a great circle, all round the earth: it divides the earth into two equal parts, called the northern and the southern hemispheres. The north pole is the middle point of the northern hemisphere, the south pole the middle point of the southern.—The equinoctial circle in the heaven is directly over the earth's equator, and divides the heaven into two equal parts, called its northern and southern hemispheres. The poles of the heaven are directly over the poles of the earth.

At the equinoxes, the earth's axis inclines neither toward the sun, nor from him: at the solstices (which are the middle days of summer and winter) it inclines $23\frac{1}{2}$ degrees toward or from the sun, according as it is summer or winter in the given hemisphere.

At the equinoxes, the sun is in the equator: at the solstices he is $23\frac{1}{2}$ degrees from the equator.

When the sun is in the equator, he enlightens the earth from pole to pole. At all other times, he shines as many degrees round the pole which is turned toward him, as he is diſtant from the equator toward that pole. And juſt ſo many degrees is the oppoſite pole involved in darkneſs.

The ſun is on the north ſide of the equator from the 20th of March to the 23d of September: and on the ſouth ſide of the equator from the 23d of September to the 20th of March.—By theſe two propoſitions it is plain, that at the poles there is but one day and one night in the whole year.

The northern tropic is a circle $23\frac{1}{2}$ degrees on the north ſide of the equator; the ſouthern tropic is a circle $23\frac{1}{2}$ degrees on the ſouth ſide. Theſe are the limits of the ſun's greateſt north and ſouth declinations.

The polar circles are $23\frac{1}{2}$ degrees diſtant from the poles, all around. When the ſun is in the northern tropic, the whole ſpace within the north polar circle is enlightened, and all within the ſouth polar circle is in darkneſs: the contrary, when the ſun is in the ſouthern tropic.—All theſe things are plainly ſhewn by the *Orrery*.

The meridian of any given place is a ſemicircle paſſing through that place, cutting the equator at right angles, and terminating in the poles.

The earth's circumference is 360 degrees; and as the earth turns round its axis from the ſun to the ſun again, in 24 hours, each meridian revolves 15 degrees in an hour; for 24 times 15 is 360.

Every place, whoſe meridian is eaſtward 15, 30, 45, 60, or 75 degrees (and ſo on, increaſing by 15) from the meridian of any given place, has noon, and every other hour, one, two, three, four, or five hours (and ſo on in proportion) ſooner than the like hour is at the given place: if weſtward, ſo much later.

The longitude of any place is the number of degrees intercepted between its meridian and the meridian of any given place from which the longitude is reckoned:

koned: and is eaſt or weſt, according as that place is eaſt or weſt from the meridian of the given place.

The eclipſes of Jupiter's ſatellites afford a method of finding the longitude, according to the obſerved times of their happening, as ſeen from different places of the earth.—Thus, ſuppoſing an eclipſe of any ſatellite to happen at ſix in the morning at London; and that it was ſeen at another place at four in the morning: the difference of time is two hours, which anſwers to 30 degrees. Conſequently, the meridian of the place where the eclipſe was ſeen at four in the morning is 30 degrees weſt from the meridian of London, where the ſame eclipſe was ſeen at ſix in the morning.

The ſame eclipſes ſhew, that the motion of light is not inſtantaneous, but that it takes about 16 minutes to travel through a ſpace equal to the diameter of the earth's orbit. For, when Jupiter is nearly in conjunction with the ſun (that is when the ſun is between the earth and Jupiter) theſe eclipſes happen 16 minutes later than when Jupiter is in oppoſition to the ſun, which is, when the earth is between the ſun and Jupiter. In the latter caſe, the earth is nearer to Jupiter by the whole diameter of its orbit (which is 162 millions of miles) than in the former. Therefore, as the ſun is nearly in the center of the earth's orbit, and his mean diſtance from the earth is 81 millions of miles; and ſince light moves through a ſpace equal to the whole diameter of the earth's orbit in 16 minutes, it moves from the ſun to the earth in eight minutes; which is almoſt as far as a cannon-ball would go in 20 years.—Hence it appears, that light moves at the rate of 592,180,000 miles in an hour; 9,869,666 miles in a minute; and 164,494 miles in a ſecond; which is 10,210 times as faſt as the earth moves in its annual orbit.

LECTURE XI.

On ASTRONOMY.

THE moon turns round her axis in the ſame time that ſhe goes round the earth in her orbit, and therefore, ſhe always keeps the ſame ſide toward the earth.

Her periodical revolution, or time of going round from any point of her orbit to the ſame point again, is 27 days 7 hours 43 minutes.

Her ſynodical revolution, or time from change to change, is 29 days 12 hours 44 minutes; which is the length of her day and night taken together: for, as ſeen from the ſun, ſhe turns only once round her axis in that time.

If the earth had no progreſſive (or annual) motion round the ſun, the ſame point of the moon's orbit would always keep between the earth and the ſun: and then there would be no difference between her periodical and ſynodical revolution; for ſhe would always change in the ſame point of her orbit.

But, as the earth is in motion round the ſun, and the ſigns of the moon's orbit always keep parallel to the like ſigns of the fixt ecliptic; a different part of the moon's orbit will be every day between the earth and the ſun from that which was ſo on the day before: and, therefore, the moon muſt move as many degrees more than round her orbit, between any change and the next following, as the earth has advanced in the ecliptic during that time; which is $29\frac{1}{10}$ degrees.

As the moon goes quite round her orbit in 27 days 7 hours 43 minutes, and the earth goes round the ſun but once a year, the earth's axis has all the different poſitions to the moon in the time ſhe goes round her orbit, that it has to the ſun in one year.

The

The moon ſhines only by reflecting the ſun's light; for if ſhe was a luminous body, ſhe would always appear round, as the ſun does.

A luminous body can enlighten only one half of a dark globe at once: therefore, at any given moment, the ſun can enlighten only one half of the moon.

When the moon is between the earth and the ſun, ſhe diſappears, becauſe her unenlightened ſide is then toward the earth. When ſhe is oppoſite to the ſun, ſhe appears full, becauſe her illuminated ſide is then toward the earth. When ſhe is 90 degrees, or a quarter of a circle, diſtant from the ſun, ſhe appears half full; becauſe one half of her enlightened ſide is then toward the earth.

The earth and moon are mutually moons to each other: but the earth gives 13 times as much light to the moon, as the moon gives to the earth; for the earth's ſurface is 13 times as big as the moon's.

In conſiderable latitudes, the different parts of the ecliptic riſe at very different angles with the horizon.—In northern latitudes, the ſigns *piſces* and *aries* riſe with the ſmalleſt angles, *virgo* and *libra* with the greateſt. Therefore,

When the moon is in *piſces* and *aries*, ſhe riſes nearly at the ſame hour for ſix or ſeven days together: but when ſhe is in *virgo* and *libra*, ſhe riſes ſo much later every day, as to differ eight hours in ſix or ſeven days.

In our winter, the moon is in *piſces* and *aries* about the time of her firſt quarter, and riſes about noon: but her riſing is not then taken notice of, becauſe the ſun is above the horizon.

In ſpring, the moon is in *piſces* and *aries* about the time of her change; and as ſhe then gives no light, her riſing cannot be perceived.

In ſummer, the moon is in *piſces* and *aries* about her third quarter; and then, as ſhe riſes not till about midnight, her riſing paſſes unobſerved, eſpecially, as ſhe is ſo much on the decreaſe.

In autumn, *piſces* and *aries* are oppoſite to the ſun; and therefore, the moon is then full in them, and riſes immediately after ſun-ſet for ſeveral evenings together; which makes her riſing very conſpicuous, as it is ſo benefical to the farmers, in affording them an immediate ſupply of light after the going down of the ſun, for reaping the fruits of the earth.

LECTURE XII.

On ASTRONOMY.

ALL the planets and ſatellites are enlightened by the ſun, and caſt ſhadows toward that part of the heaven which is oppoſite to the ſun as ſeen from them.

If the ſun and earth were equally big, the earth's ſhadow would be infinitely extended; and always of the ſame bulk, and would do more than cover the planet Mars when oppoſite to the ſun, becauſe Mars is much leſs than the earth.

If the earth were bigger than the ſun (and to us it ſeems to be the biggeſt body in the univerſe) its ſhadow would ſtill be the bigger the farther it extended; and would even cover Jupiter and all his moons, when Jupiter is oppoſite to the ſun.

If the ſun be bigger than the earth, the ſhadow will be of a conical figure; and end in a point at a certain diſtance from the earth.

But the earth's ſhadow never reaches Mars, although that planet, when oppoſite to the ſun, is not above 42 millions of miles from the earth; which demonſtrates, that the ſun is much bigger than the earth.

The moon is eclipſed, when ſhe falls into the earth's ſhadow. Therefore, ſhe can never be eclipſed but at the time of her full; becauſe, that is the only time of her being oppoſite to the ſun. If ſhe were a luminous body, ſhe could not be darkened by the earth's ſhadow. For, a candle will ſuffer no diminution of its light, by being placed in the ſhadow of a board, or globe, enlightened on the oppoſite ſide by another candle.

The ſun is ſaid to be eclipſed, when the moon paſſes directly between him and any part of the earth; which can only be at the time of new moon. But, although the moon may then hide the ſun from part of the earth, and *that* part muſt be darkened, becauſe the moon's ſhadow covers it; yet, as ſhe does not take ſo much as a ſingle ray of light from the ſun, the ſun, ſtrictly ſpeaking, is never eclipſed by the moon; any more than by the convexity of the earth, when it hides him from out ſight. Notwithſtanding, when the moon hides the ſun, or any part of him, from our ſight, we ſay, the ſun is eclipſed.

If the moon's orbit lay in the * plane of the ecliptic (in which the earth always moves) the ſun would be eclipſed at the time of every new moon; and the moon would be eclipſed at the time of every full.

But one half of the moon's orbit is on the north ſide of the plane of the ecliptic, and the other half on the ſouth ſide of it. Therefore, the moon's orbit cuts the plane of the ecliptic only in two oppoſite points, which are called *the moon's nodes.* The angle of the moon's orbit with the ecliptic is 5 degrees 18 minutes.

* If a circle be drawn on a piece of ſmooth flat paper, the paper may be juſtly called the plane of that circle.

When the moon is any thing more than 12 degrees from either of her nodes at the time of being full, ſhe paſſeth clear of the earth's ſhadow; and therefore ſhe cannot be eclipſed at that time. But when ſhe is within 12 degrees of either node at full, ſhe is eclipſed; and if ſhe be in either of the nodes, the eclipſe will be central.

When the moon is any thing more than 18 degrees from either of her nodes at the time of change, ſhe either paſſeth above or below the ſun; and therefore the ſun cannot be eclipſed at that time. But when ſhe is within 18 degrees of the node at the time of change, ſhe eclipſeth the ſun to ſome part of the earth. And if ſhe be in the node, the eclipſe will be central to that point of the earth's ſurface which is in a right line between the ſun's center and the earth's.

If the moon's nodes kept always in the ſame ſigns of the ecliptic; in whatever ſigns the ſun and moon were eclipſed in any given year, they would be ſo in every year after.—But the eclipſes fall back every year, from the conſequent towards the antecedent ſigns, in ſuch a manner as to prove that the moon's nodes move backward $19\frac{1}{3}$ degrees every year: and therefore, in 18 years 225 days, they move backward through all the ſigns and degrees of the ecliptic.

From the time of the ſun's being in conjunction with either of the moon's nodes, to the time of his being in conjunction with the other, is 173 days. If the nodes had no motion, the interval between theſe conjunctions would be $182\frac{1}{2}$ days, or half a year.

In 18 years 11 days 7 hours 43 minutes, there is a conjunction of both ſun and moon with the ſame node. And therefore, in that time, there is a period or reſtitution of the ſame eclipſes.

The

The darkneſs at our SAVIOUR's crucifixion could not poſſibly be occaſioned by a natural or regular eclipſe of the ſun; for it was at the time of the paſſover, which was always kept at the time of full moon.

He was crucified on the day next before the Jewiſh ſabbath, which being kept on our Saturday, the Crucifixion was on Friday. So that the paſſover full moon in that year was on a Friday.

But it appears by calculation, that there was only one paſſover full moon on a Friday from the 20th to the 40th year of our Saviour; and *that* particular full moon was on the third day of April, in the 33d year of his age, accounted from the vulgar æra of his birth.

The 33d year of Chriſt was the 4746th year of the *Julian* period, and the fourth year of the 402d *Olympiad*.

Phlegon, a heathen writer, tells us, that in the fourth year of the 402d Olympiad, there was the greateſt eclipſe of the ſun that ever was known; and that "*it was night at the ſixth hour of the* "*day*."

Ptolemy's canon fixes the year, in which the commandment was given to *Ezra* by *Artaxerxes Longimanus*, to reſtore the ſtate of the Jews, to the year of the *Julian* 4256: and, according to *Daniel*'s prophecies, the death of CHRIST was to be at the end of 70 annual weeks, or 490 years, after that time.

And 490 years being added to 4256, makes 4746; the above year of the *Julian* period, which we prove aſtronomically to have been the prophetic year of our Saviour's death; concerning which, we have the teſtimony of a heathen writer, who, being not an aſtronomer, miſtook a ſupernatural darkneſs for an eclipſe of the ſun.

FINIS.