and as the moon's attraction at the earth's centre, keeps the earth from flying out of this monthly circle, it must be greater than the centrifugal force of the water on the side next her, and consequently her greater degree of attraction on that side is sufficient to raise them; but as her attraction on the opposite side is leſs than the centrifugal force of the water, the exceſs of this force is just sufficient to raise the water as high on the opposite side. From the principles thus established, it is evident that the earth moves round the sun, and not the sun round the earth; for the centrifugal law will never allow a great body to move round a leſs in any orbit whatever and it is well known that the quantity of matter in the sun is 227.000 times as great as in the earth. All globular bodies whose parts can yield, and which do not turn on their axis, must be perfect spheres, because all parts of their surfaces are equally attracted towards their centres. But all such globes that do turn on their axis, will be oblate spheroids, i.e. their surfaces will be higher, or farther from the centre in the equatorial, than in the polar regions; for in the former, the centrifugal force is greatest. The equatorial diameter of the earth is 36 miles longer than its axis. The earth then being higher at the equator than at the poles, the sea would run towards the polar regions, and leave the equatorial parts dry, if the centrifugal force of the water which carried it to these parts, did not detain it, and prevent its returning again towards the poles of the earth.

Lecture VIII.

Of Bodies falling perpendicularly,
or
Of the nature of that motion which bodies acquire in falling freely from a state of rest.—

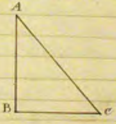
The accelerated force of gravity is measured by the spaces paſsed through in a given time.

The attractive force of the earth causes a motion uniformly accelerated because the power of gravity acts constantly and uniformly upon bodies.

The velocities acquired at the end of any given times, are as the times.

The spaces paſsed over with an uniformly accelerated motion are as the squares of the times. Thus a body will fall 4 times as far in two minutes as it does in one, 9 times as far in 3, 16 times in 4, and so on.

The space which a body falling freely describes, is expreſsed by a right angled triangle in the following manner. Let the perpendicular expreſs the time, and the bottom line the velocity: then will the area of the whole triangle expreſs the space paſsed thro: AB expreſses the time, BC the velocity, and the area ABC the space.



From this proposition may be deduced the following corollaries. 1st. The space paſsed over in any time from the begining of the fall, is half what the same body would describe in the same time with the last acquired velocity. This is plain, for in half the time it has but half the force, and by the last acquired velocity it is equal to the whole time. 2nd The spaces are as the squares of the times, or of the velocities. It has been shown that the spaces are as the squares of the times, and the velocities are as the times; therefore the spaces are as the squares of the velocities. This is proved by a right angled triangle. 3rd. A body moves three times as far in the second portion of time as in the first, five times as far in the third, seven times in the fourth &c. If a body moves over a certain space in the first portion of time, in the second, the acquired velocity will be great enough to carry it twice that distance, and the force of gravity adding another distance, will make the space run over in the second portion of time three times as great as that perceived in the first &c. 11th. The accelerated motion of a falling body approaches nearer and nearer to an uniform motion. This is evident, since the spaces descended through in each second are as the odd numbers 1, 3, 5, 7 &c. and as these numbers approach nearer and nearer to an equality, so the accelerated motion of a falling body will continue to become more and more uniform, without a poſsibility of ever becoming perfectly so.

Bodies thrown upwards are retarded continually by the force of gravity, inversely as the squares of the distances increase. The time of ascent is equal to the time of descent. If a body be thrown upwards with a velocity equal to that which it would acquire by falling through a given hight, it will rise to a hight equal to the given hight.

The hights to which bodies rise, are as the squares of the times spent from their first setting out to the moment they cease to rise. Thus if a body be thrown with such a degree of velocity as to continue rising twice as long as another, it will ascend four times as high, if thrice, nine times as high &c.

Height or depth may be determined by falling bodies. If we want to know the hight of an object, we have only to let fall a bullet from its top and ascertain by means of a pendulum the number of seconds it employs in reaching the bottom.

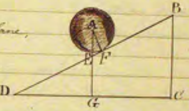
The denser the medium is, the sooner an uniform motion will be acquired. thus a body falling in air will be longer acquiring an uniform motion than in water, and longer in water than in quicksilver. Bodies of the same density and figure will sooner come to an uniform motion according as their magnitudes are leſs: for the quantities of matter increase in bodies with the cubes of their diameters, but the surfaces increase only with the squares of the diameters, and since the resistance is in proportion to the surfaces of bodies moving in the same medium with the same velocity, it follows that smaller bodies will be more resisted in proportion to their size, and so come sooner to an uniform motion. If bodies move in the same medium with different velocities, those which move fastest will sooner acquire an uniform motion, because the resistance increases with the squares of the velocity.

All bodies thrown upwards describe a parabola, tho' they appear to ascend and descend in right lines; for they are urged by two forces, the projectile upwards, and the force arising from the motion of the earth about its axis from W. to E. in which case it must neceſsarily describe a parabola.

Of bodies descending on inclined planes.

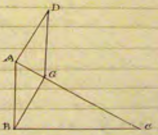
When a body descends on an inclined plane, its motion is continually accelerated by gravity, but in a leſs degree than when it descends perpendicularly; whence it follows, that what was said concerning the perpendicular descent of bodies is true of such as fall on oblique planes, allowance being made for the difference of acceleration.

The effect which gravity has on a body falling down an inclined plane, is to that which it exerts on another falling freely, as the perpendicular height of the plane, to its length.



Let A be a body upon an inclined plane, and from its centre let AG be drawn perpendicular to the horizon DC, and AF perpendicular to the inclined plane DB. Then, AE represents the whole force of gravity, and EF that part of it, which urges the body down the plane. And the triangles AEF, DBC being similar, (Eucl. prop. 29. Book 1.) EF: AE:: CB: BD, which makes the proposition abundantly manifest.

This is otherwise demonstrated as follows. Let AC be the inclined plane, the body at A, and the action of gravity whereby it endeavours to fall perpendicularly represented by the line AB: let AD be perpendicular to AC; AD will then represent the direction by which the plane acts upon the body. (for all bodies act in lines perpendicular to their surfaces); let then these two forces be resolved into one in the direction AG by compleating the parallelogram BD, whose diameter will be AG. In order to this BG must be let fall perpendicularly upon AC that it may be parallel to the opposite side AD. Consequently (Eucl. prop. 8. bk. 6.) AG: AB:: AB: AC, i.e. the tendency of the body down the plane, is to its perpendicular tendency, as the perpendicular height of the plane to its length.



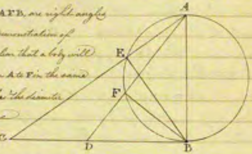
The space thro' which a body falls down the oblique side of a plane, is to that through which it would fall perpendicularly in the same time, as the perpendicular height of the plane is to its length. Thus a body would fall from A to G, in the same time that it would fall from A to B, because AB: AC:: AG: AB.

The velocity a body acquires by falling perpendicularly, is to that it acquires in the same time by falling obliquely, as the space of its perpendicular descent, is to that of its oblique one.

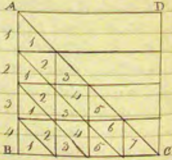
As the length of the inclined plane, is to its height, so is the time in which a body descends along the one, to the time in which it falls through the other

If a body descends along an inclined plane, and another falls thro' its perpendicular height, they will both have acquired the same velocity.

A body takes up the same time in falling thro' the chord of a circle, whether it be long or short, that it does in falling thro' the diameter; and also, the same time in falling thro' any chord whatever.



The angles AEB, AFB, are right angles (Eucl. prop. 31 Book 3) By the demonstration of the first proposition, it is clear that a body will fall from A to E, or from A to F in the same time that it would fall thro' the diameter AB. Now AE and AF are chords of the circle AFB; therefore a body will fall thro' any chord of a circle in the same time that it would fall thro' the diameter of that circle.

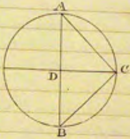


The space paſsed over in any time, reckoning from the begining of the fall, is equal to half what it would describe in the same time moving with the acquired velocity. For AB×BC = the whole square ABCD which is twice the triangle ABC. Now AB represents the time of falling, BC the last acquired velocity, and the triangle ABC the space paſsed over in the first portion of time.

From this figure it is evident that the spaces paſsed thro' are as the squares of the velocities or times. For we see that the spaces or different triangles contained in the large triangle ABC are 16 in number, which is the square of the times, and also of the velocities.

It is also plain that a body moves three times as far in the second period of time as in the first, 5 times as far in the third, 7 times as far in the fourth &c. For else, it could not fall 4 spaces in two minutes, 9 in three &c. as the figure represents.

That a body will fall thro' the chord of a circle BC in the same time that it will fall thro' the diameter AB, may be demonstrated in the following manner.



$$AB : BD :: AB^2 : BC^2$$

Taking square roots, — $\sqrt{AB} : \sqrt{BD} :: AB : BC$.

But, time $AB : T\,BD :: \sqrt{AB} : \sqrt{BD}$.

Hence, time AB : time $DB :: AB : BC$.

But, time CB : time $DB :: CB : DB$ that is, $:: AB : BC$.

Then we have, time AB : time $DB :: AB : BC$.

time CB : time $DB :: AB : BC$.

Therefore time AB = time CB.

Lecture IX.

Of Pendulums.

A Pendulum is a body suspended from a point and moveable about that point as its centre. It may be either a straight piece of wood, or other solid substance; or it may be a body suspended by a string.

The theory of pendulums depends upon the same proposition established in the last lecture, viz. that a body takes up the same time in falling thro' one chord of a circle as another.

An oscillation is the whole arch described by a body suspended from a point as its centre, and a vibration is the same.

The curves described are cycloids, and they are described in nearly equal times.

The vibrations of a pendulum would be precisely equal if described in chords of circles, and they approach more nearly to an equality in small than in large arches, because small arches differ less from their chords than large ones.

The times of vibration are not affected by the weights of pendulums, because the heavier they are, the greater force is required to move them. The lightest will come to rest soonest, and the shortest will vibrate quickest.

The length of a pendulum which vibrates seconds, is 39. 2 inches.

The times wherein pendulums of unequal lengths, vibrating in similar arches, perform their vibrations, are as the square roots of their lengths; that is, a pendulum of four times the length of another, will vibrate only in half the time, one of 16 times the length, only in a fourth of the time &c.

The time of vibration in different pendulums, is equal to the time in which a body falling freely would descend thro' eight times the length of the pendulum; supposing that pendulum to vibrate in the chord of a circle. For a body in descending acquires a velocity sufficient to carry it as high as the point from which it fell. But the time of the pendulum's descent only is equal to that in which a body would fall thro' the diameter of the circle. In twice that time, therefore, that is, in the time of descent and ascent, or of one whole vibration, the body will fall four times as far, i.e. four times the diameter of the circle of which the pendulum is the radius or half diameter. Therefore the body will fall thro' 8 times the radius, or length of the pendulum, during one vibration.

The length of a half second pendulum is 9.8 inches.

The centre of oscillation in any pendulum is that point which if impeded, the vibration will cease without any jar to the pendulum.

An uniform rod will perform its vibrations in the same time with the second pendulum, when it is one third longer, because then their centres of oscillation are equally distant from the points of suspension.

The number of vibrations in a given time by different pendulums, is proportional to their lengths. We may determine the vibrations by extracting the square roots of the lengths of the pendulums; for the times of vibration are as the square roots of the lengths.

The same pendulums do not vibrate in the same time in all seasons and climates. This arises from two causes; 1st. They expand by heat and contract by cold. 2nd The force of gravity is not the same in all countries, being greater at the poles than at the equator. The attraction is [illegible] greater at the poles, than at Paris.

The sun and a well regulated clock will agree four times in the year, 14th April, 15th June, 31st August, & 24th December. From 14th Apl. to 15th June the sun is before the clock; from then till 31st August, the clock is before the sun; from then till 24th Dec., the sun is before the clock, and from then till 14th April, the clock is before the sun.

The great use of pendulums is the accurate method of measuring time which they afford. Time is not an object of our perception. We are not capable of judging of it so nicely, as accurately to compare one portion of it with another. A succeſsion of pleasurable ideas, or a painful suspense, may make the same portion of time appear to us longer or shorter than it really is. Hence it is requisite, that we should resort to some method, which shall render the paſsing of time visible to our senses. Motion is most applicable to this purpose, since it has a very evident analogy to the eternal succeſsion of time.

The ancients had many methods of measuring time. From the rising to the setting of the sun, and from his setting to his rising. From the revolution of the moon round the earth, and by a year. The Jews reckoned 12 hours between the rising and setting of the sun, and 12 hours between the setting and rising. Hence their diurnal and nocturnal hours were seldom of equal length, as the length of the days and nights is not equal, except at the equinoxes. Time was formerly measured by the running of sand or water thro' glaſses which had a certain quantity. But this method is subject to many inaccuracies and inconveniences owing to friction, to external circumstances operating so as to make the sand or water run faster than usual; and, where water is used, to the different degrees of evaporation, arising from the difference of the weather; lastly, to the inconveniency of constantly replenishing the vessel made use of. The motion of the pendulum is so regular as to obviate all the inconveniences.

The sources of error in every experiment that has been made (such as the dropping of water, and falling of sand) are obvious from what has been already said. The sources of error in the modern manner consist in the different effects of climate, attraction of the earth &c.

The idea of a pendulum was first suggested to Gallileo by the swinging of a lamp in his room. It was first applied to clocks by Huygens.

There are several kinds of pendulums. One is a straight rod with a nob at the end. The pendulum used by Rittenhouse was a glaſs rod. Glaſs is most affected by heat and cold, but is most regular in its affections. By applying a thermometer to it, he knew the degree of expansion or contraction, so that by making a proper allowance for the error, he arrived at the greatest certainty. Some particular kinds of wood, such as deal wood, sapadillo, &c are very little affected by heat and cold, and therefore make very good pendulum rods. A glaſs tube filled with mercury has also been used, and is by some thought best: because while the glaſs lengthens by heat, the mercury rises in the tube, so as to preserve the centre of oscillation in the same point: and when the cold shortens the tube, the mercury condensed falls and thus produces a similar effect. There is another kind of pendulum which is represented by the figure below. At every one of these corners there is a joint. When the iron expands they counteract the expansion by drawing up and forming a more acute angle; so that what it gains by expansion it loses by contraction.

The grid iron pendulum is an excellent contrivance. Bishop Madison's illustration of it, is as follows. Let CD be one third of the length of AB and EF together, and let it be made of metal which contracts or expands three times as much as the metallic rods AB & EF. The pendulum will always be of an uniform length. AB & EF are of the same metal.

Mr. J. suggested the following observation in regard to a principle in pendulums. "We know that a body will fall thro' 16 feet in the first second of time: but in the same time, a pendulum 39 2/10 inches will perform a vibration. During the time, taken up in performing this vibration, a body will fall thro' 8 times the length of the pendulum; i.e. in one second of time, a body will fall thro' 8 times 39 inches, without calculating fractions. 39×8 = 312 inches ÷ by 12 = 26 feet. Therefore the body will fall thro' 26 feet in one second: but it is known that it will fall thro' only 16 feet. This contradiction between two principles, both so well established to all appearances, is strange and remains yet to be reconciled." — The following is Bishop Madison's answer.

Dear Sir,

The descent along the chord of any circle is certainly performed in the same time, as the descent along the diameter of that circle. It follows then that the whole vibration, or the fall and rise of two chords, taking up twice the same time, that a body would fall thro' four diameters; that is, thro' 8 times the length of the pendulum. But a body will fall faster in an arch than a chord, & it has been demonstrated, that the time of the fall in an arch, is to that in its chord, nearly in the proportion of 786 : 1000. There is also a remarkable experiment of Desaguliers mentioned by Adams — by which he found that a leaden ball fell thro' 272 feet in 4″ 30‴, whereas from the theory, it ought to have descended thro' 323. 5 inches. This difference arose from the resistance of the air, as Desaguliers has shewn. We must apply these two principles and observe the result. First, 39.2+8 = 313.6, which by 12 = 26.13 feet. This would be the space thro' which a body would fall according to the proposition, in one second of time.

Apply the first correction.—1000:765::26.13:20.51
Apply the second correction.—325.6:272::20.5:17.1.

You see then by these corrections, that the 26.13 feet are reduced to 17.1 feet.—But, by a writer of great eminence, it may be reduced still farther, viz. McLaurin; for he observes, that the time in a small arch, is not the same with the chord, tho' the arch be equal to its chord. According to him, the time is nearly as as 4:3. But, 4:3::26.13:19.8. instead of 20.51;—and as 325.6:272::19.8:16.5 feet—.——

This last, you observe, coincides very nearly with the actual experiment—

Believe me to be
Yours respectfully
J.M.

January 1st 1800

Mr. Henry St. G. Tucker

The pendulum is of still farther use. By its assistance we may very conveniently and accurately measure distances. Suppose we wish to measure the distance of one house from another. Let a gun be fired at one of them, and let a person standing at the other, count the number of vibrations of a second pendulum from the time he sees the flash to the time he hears the report. Sound passes over 1142 feet in a second. Multiply the number of the seconds by 1142 & you have the distance between the two houses in feet.

The pendulum affords an universal standard of measure. Thus—Let the second pendulum be divided into an hundred parts, and let any nation take so many thereof for its foot; they have thus an universal measure of distance. Let these feet be divided into inches, and let a piece of lead of so many square inches for instance 3, be a pound all the world over; in this manner you have a standard of weights—Let a bushel be so many of these feet deep, so many in circumference &c, and by this means we have a standard measure of quantity.——

Lecture X.

Of the Mechanical powers.

The object of mechanics is to investigate the means whereby the laws of motion are applied to the construction of machines whether simple or compound, so as to save time, or increase power. That branch of it which considers the equilibrium of bodies is called statics, that which treats of motion dynamics. The knowledge of mechanics, is one of the distinguished privileges by which civilized nations are exalted above those in a state of barbarism. The force of man, tho' naturally very limited, is by this art rendered so great as to leave nothing beyond his reach. His mental powers, by means of this science, in a great measure compensate for the deficiency of his corporeal. Without an acquaintance with mechanics, man would be a feeble animal, exposed to every kind of danger; whereas by a knowledge of it, he is armed against the inclemencies of the seasons, & furnished with all the conveniencies, as well as luxuries of life. Houses, Ships, Carriages, the impliments of husbandry, and, in short, machines of every kind, owe either their origin, or improvement to this science.

Philosophers have distinguished mechanics into practical and rational. the former treats of the mechanical powers, the latter of the theory of mechanics. the mechanical powers are six in number, the Lever, the Wheel and Axle, the Pulley, the Inclined plane, the Wedge, and the Screw. There are three things to be principally considered. 1st the power. 2nd The weight to be raised. 3rd the machine which raises it. There are also two principle problems to be resolved. 1st The proportion the power must bear to the weight in order to produce an equilibrium. 2nd The proportion which will produce the greatest possible effect. Many writers on mechanics have treated of the first, and only a few of the latter, altho' it is of much importance.

There is a universal rule for determining when the balance will take place between the weight and power. It is as follows — The power must be to the weight, as the velocity of the weight to that of the power; or, the power multiplied by its velocity, must be equal to the weight multiplied by its velocity; or, the velocities of the power and weight must be inversely as their quantities of matter. This rule depends on the equality of momenta, which is a fundamental principle in mechanics. How, it may be asked, is the equipoise to be produced, when there is no motion? The answer is, that the tendency to move must be taken into consideration. In order to compute the force and advantages gained by a mechanical engine, we must ascertain how much swifter the power moves than the weight. Four things must be carefully attended to. 1st The power. 2d The weight. 3d The centre of motion. 4 the velocity. The opinions of philosophers have been various as to the number of the mechanical powers. Some have made them seven by reckoning the balance, others six by rejecting the balance, and others again five by leaving out the screw as a species of inclined plane. This variation of opinion among writers is not worth attending to, nor is there any necessity for it, because the difference is nothing more than the same principle applied differently. — They are called simple machines, because they consist of a simple piece. The theory of mechanics makes no allowance for friction, but supposes all planes to be perfectly smooth.

Of the Lever.

In theory it is to be considered as an inflexible right line having no weight. According to common use, it is a solid bar, one part of which is supported by a steady prop called the fulcrum, about which as the centre of motion the lever is moveable. The balance takes place, when the power and weight are inversely as their distances from the fulcrum. The iron crow is a bent lever acting upon the same principle: the balance is produced in the same way, and very little additional force is necessary to raise the weight. There are three kinds of levers. 1. When the prop is between the power and weight. 2. When the weight is between the power and prop. 3. When the power is between the prop and weight. The balance is produced in each on the principle already mentioned. The advantage gained by each is proportional to the excess of velocity in the power, over the velocity of the weight; or as the ratio of the distance of the power from the prop, to the distance of the weight from the prop. There are three cases of the lever. 1st When the weight and power are known, the distance at which they will be in equilibrio, may be found by dividing the weight by the power. 2d When the distance is known, the power may be found by dividing the weight by the distance. 3d. The weight may be found by multiplying the power by the distance.

To the three kinds of levers above enumerated, a variety of instruments are reducible. To the first belong scissors, snuffers, &c. which are made of two levers acting in opposition to each other. To the second kind are reduced, oars, rudders of ships, doors turning upon hinges, and the like. We may observe as to oars, that the boat is the obstacle to be overcome, and the water the point upon which the oar turns. This lever shews why, if two men carry a burden upon a stick between them, the share of it borne by each is inversely as his distance from it. This lever illustrates also, the case of two horses required to be so yoked as that each may draw a part proportionate to his strength; which is done by dividing the beam they pull in such a manner that the point of traction may be as much nearer to the stronger horse than to the latter, as the strength of the former exceeds that of the latter. A pair of tongs may be given as an instance of the third kind. The bones of a man's arm may be also given; for when we lift a weight by the hand, the muscle that exerts its force to raise the weight, is fixed to the bone about one tenth part as far below the elbow as the hand is; and the elbow being the centre round which the lower part of the arm turns, the muscle must therefore exert a force ten times as great as the weight that is raised. The jaw bone affords another remarkable instance; and here it is curious to observe, that when a boy goes to crack a walnut, he always puts it as far back as poſsible in order to gain the greater length of lever. —— This lever shews why the most active men are those who have long thighs, short legs, and small feet; for when this is the case, the muscles have leſs weight to raise in proportion to their strength. We see also, why long thighs and short legs in a horse, may be esteemed as a sure sign of swiftneſs. The manner in which we raise a ladder against a wall, is another instance which deserves particular attention.

The Roman statera, a steelyard, is a lever of the first kind, and is used for finding the weights of different bodies by one single weight placed at different distances from the prop or centre of motion. The two arms (one of which is a great deal shorter than the other) are made to balance each other. The longer is divided into as many parts as it will contain, each equal to the shorter. Hence it is evident, that the same counterpoise, by different positions, may be made to balance either its own weight, or as many times its own weight as there are divisions in the longer arm; for if it be placed at the distance of one division from the centre of motion it will just balance its own weight, at the distance of two divisions it will balance twice its own weight, and so on.

The balance tho' not a mechanical power, deserves however to be spoken of particularly. It affords no mechanical advantage because the beams are of equal length. The best is that which cæteris paribus, vibrates most freely. Balances have been carried to such perfection in England, as to determine a difference of the one million six hundredth part of a grain. Their essential parts are, the arms, the centre of motion, and the tongue. To render this instrument exact, the arms should not only be of equal weight, but of precisely the same length; and the centre of motion should be immediately above the axis of the centre of gravity, that the arms may not be in equilibrio in any other but an horizontal position. A curious property of the balance is, that a man in a scale may cause **himself** to descend by pushing against the beam near the centre of motion. The reason is, that his force is exerted on some intermediate part of the beam; for as it must react equally upon the scale, which is farther distant from the centre of motion, it will of course cause him to descend. The deceitful balance is formed by making the arms of different lengths, tho' of the same weight. In this case the scales when empty will balance each other; but if equal weights be put in each, the scale farthest from the centre of motion will preponderate.

The Wheel & Axle.

The wheel and axle consists of a cylinder and wheel fastened to the cylinder, all moveable about a common axis. In this machine the power is applied to the circumference of the wheel, and the weight is raised by a rope which coils about the axle as the wheel is turned round. The balance is produced when the power is to the weight as the circumference of the axle to the circumference of the wheel. It is plain that the velocity of the power exceeds that of the weight, just as much as the circumference of the wheel exceeds that of the axle, and the advantage is proportional to this excess. viz. the smaller the axle, and greater the circumference of the wheel, the greater will be the mechanical advantages. The wheel and axle may be reduced to an advantageous lever of the first kind. — We must take into consideration the rope, but whether the whole thickneſs or only half of it, is not agreed upon by philosophers.

The Pulley.

A pulley is a solid piece of wood or other solid substance fixed in a block or frame, and moveable about a centre pin as its axis. A single pulley does not produce any increase of force, but only serves to change the direction of the power. If we substitute a lower block, the power gained will be as two to one. If we have two above and two below, it will be as four to one. In all cases the advantage seems to be, as one to the number of ropes, or to twice the number of pulleys in the lower block. The advantages are to be estimated according to the number of ropes or pulleys, or according to the difference in the velocities of the power and weight. Each pulley may double the action of the power, when they are placed in such a manner that the first may move half as fast as the power, the second half as fast as that, and so on. We have made no allowance for friction, which however is very great, and constitutes the great disadvantage of the pulley. It arises from three causes. 1. The great proportion which the diameter of the axis bears to that of the pulley. 2. The pulleys are apt to rub against each other or against the sides of the block. 3. The swiftneſs of the rope.

The Inclined Plane.

The inclined plane is nothing more than a plane inclined to the horizon. Its advantages are as the length of the inclined plane to its perpendicular height. The balance is produced when the power is to the weight as the length of the plane to its height. Every thing is here considered as moving with perfect freedom.

The Wedge.

The wedge is to be considered as a double inclined plane, or two inclined planes joined base to base. This will appear obvious if we suppose the wedge to be divided lengthwise into two equal parts. Writers differ as to the manner in which the wedge acts. In all cases the advantage seems to be, as the length of the two sides to the whole back, or one half of the back to one of the sides.

The Screw.

The screw is nothing more than an inclined plane coiled round a cylinder. It cannot be considered as a simple machine, because it is never used without a lever or winch to aſsist in turning it; and then it becomes a most powerful engine, either in preſsing the parts of bodies close together, or in raising great weights. It is evident that the winch must turn the cylinder once round before the weight or resistance can be moved from one spiral to another: therefore the advantage must be estimated according to the ratio which the circumference of the circle described by the handle, bears to one spiral of the screw. This may be clearly shewn by experimt. Let the distance between the spirals be one inch, and the length of the handle ten inches: then the circumference of the circle described by the latter, will be about sixty times as great as the distance between the former; and one pound applied to the winch will balance sixty acting against the screw. Hence the longer the handle, and the nearer the spirals are to one another, the greater will be the force. In all cases the equilibrium takes place, when the power is to the weight, as the circumference described by the former in one revolution, is to the distance between two contiguous threads of the screw.

Lecture XI.

Compound Mechanics.

The combination of two or more of the mechanical powers constitutes a compound machine. An astonishing degree of force may be here gained, but it is counteracted by the slowness of the motion. This is a natural consequence of the fundamental principle laid down before, viz. that the momenta of the power and weight must be equal. What we gain in one respect, we lose in another. But altho' the loss of time be considerable, and certain bounds are prescribed to us by nature; yet the greatness of the effect produced renders this branch of philosophy particularly useful. The principle upon which an equilibrium is produced, is the same as in the simple powers, i.e. the power multiplied by its velocity must be equal to the weight multiplied by its velocity. The machines are generally compounded of the lever, the wheel and axle, and the screw. To estimate the advantage gained in a compound engine, find the separate advantages of the simple machines which compose it, multiply them into each other, and the result will be the advantage gained. To illustrate this, suppose there be a machine compounded of the lever, the wheel and axle, and the inclined plane, in which the lever gives an advantage of 4, the wheel and axle that of 6, and the inclined plane that of 2; then 4×8×2 = 64 = the whole advantage. A person at first view might perhaps be inclined to think, that were the separate advantages added together, their sum would give the compound advantage. But this is certainly a mistaken notion, for the former position may be established very satisfactorily. Suppose for instance there be a machine compounded of three levers. Let each lever give an advantage of 4, (i.e. let one oz placed on the long arm balance four placed on the short one); then the advantage of 4 which the first lever affords acting upon the second lever will increase the advantage of this lever four times; and this increased advantage, viz. of 16, acting upon the third lever will produce an effect of 64, which evidently establishes the principle laid down. The advantage would be computed in the following manner, multiplying all the antecedents together, and all the consequents.

1 : 4 1 : 2
1 : 4 as if the ratios stood as follows 3 : 7
1 : 4 2 : 5
1 : 64 6 : 70

Otherwise the effect of a compound machine is estimated by comparing the spaces passed thro', the power and effect being to one another inversely as their velocities. Thus if I find that the power must move thro' 100 feet, whilst the weight moves thro' 1, I immediately conclude that a power of one pound will balance a weight of 100. The loss of time in all compounded machines is proportionate to the excess of the velocity of the power above that of the weight. In working a machine one third more of the power which produces the equilibrium is required to be added. This is absolutely necessary, but to work the machine with the greatest possible effect, four ninths should be added. A compound machine may consist of simple ones repeated as often as you please.

The powers which have been employed as first movers of machines are principally the following. 1. The natural strength of man. 2. The strength of other animals. 3. The force of water. 4. The force of wind. 5. The elastic force of springs. 6. The simple weight of heavy bodies. 7. The elastic force of steam.

The object of the fly is to regulate the motion of the machine by accumulating the power communicated to it, and exerting it equally and gradually in every revolution. It does not, as some suppose, increase the force, but on the contrary must diminish it, from its own friction and the resistance of the air.

A variety of compound machines deserve our particular attention We shall mention, however, a few of them only. First, let us consider clocks and watches. In the former the weight, in the latter the spring is the moving force. The balance in watches answers the use of the pendulum. The force in clocks acts by gravity, that in watches elasticity. The spring differs from the weight in a very remarkable circumstance, viz. its action is never uniform. It is strongest when most bent and decreases in proportion as it unbends. To remedy this defect, the fusee has been long in use (i.e. an hollow groove of a spiral form made round a solid piece of metal) which renders the action of the spring) uniform. It is so contrived, that the decrease of force arising from the expansion of the spring is counteracted by the proportionate increase of the length of the lever whereby it acts. The use of the pendulum and balance is to govern and regulate the machine. The resistance is the friction of the various parts. The fusee should be of a spiral shape.

We shall next speak of mills, and first of three kinds of water mills that are useful in grinding of grain. They are the overshot, the undershot, and breast mill. The overshot depends on the velocity and weight of the water, the undershot on the velocity, and the breast mill on the weight only. The overshot is preferable where there is a small body of water, and a large fall in the stream; the breast mill, where there is a large body of water and a small fall; and the undershot, where the fall is very small, and the force very great. The following philosophical principles should be carefully attended to — To determine the force of the water iſsuing thro' the penstock. Find the height in feet of the water above the aperture; find also the area of the aperture in feet; multiply these together, and multiply the product by 62½ lbs, the weight of a cubic foot of fresh water. The product will give the force of the water expreſsed in lbs. To find the velocity which the water acquires by falling thro' any given height. Take the square root of the height & multiply it by 8. To find the height, divide the velocity by 8, and square the product. To find the quantity discharged. Find the velocity for 1 second, multiply it by 60 for a minute, and multiply this sum by the area and divide by 1282, the number of solid inches in a gallon. Your product will be the number of gallons discharged in a minute. The proportion which the velocity of the wheel should bear to that of the water, as commonly aſsigned is one third, but one half is better. The velocity of the running stone should be one revolution in a second. The water should strike an overshot wheel in a tangent; because considering the diameter as a lever, it acts on a point farthest from the centre of motion, and consequently has the greatest effect. The centripetal force causes the meal constantly to recede from the centre of the stone till it is thrown off and falls into the trough. The stones should be farther from each other in the middle than at the edges, and they should be furrowed so as to cut the corn.

Barker's Mill. The principles upon which it depends are, the velocity of water, the quantity which iſsues thro' the spout holes and the distance of these holes from the centre. The machine is put in motion in consequence of the preſsure of the water against the tube being diminished on those sides where it iſsues thro the spout holes. the dimensions requisite for turning the largest stone are, the arm 3 feet long, the holes 11 inches square, and the tube 6 or 8 feet high and about 8 inches in diameter. The inconvenience attending this contrivance arises from the great degree of friction of the pivot on which it turns.

Lucas's Pendulum Mill. This is contrived so as to turn by means of a pendulum. the disadvantage arises from the great degree of friction which prevents the pendulum from vibrating of itself and renders it neceſsary for some one to keep it in motion. Hence the motion of the mill will not be equable.

Wind Mills. They are principally regulated by the position of the sails. the best shape for the sails is that of a bird's wing. If they be set right against the wind, either the mill will be blown down, or they will have no power to move. they should therefore be set obliquely, and the effect will be greatest at an angle of 54° 44'. This is also the maximum angle for rudders of ships, locks, and the like. the strongest arch is the catenarian formed by a rope swinging freely between its suspended ends.

The best machine for the production of a particular effect, is that which will produce the effect in the simplest, steadiest, safest, and cheapest manner poſsible.

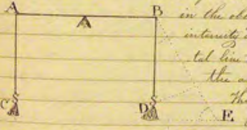
Lecture XII.

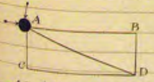
Of Wheel Carriages.

Previously to entering on the subject of wheel carriages, we shall make some observations.

1st On Oblique Forces.

In estimating the theory of machines, we pay no attention to the physical circumstances in which they differ. A direct force is that which preſses or draws to itself, the point to which it is applied, in a direct line: If it draws it in any other direction, it is called an oblique force; or an oblique force is, when the power and weight do not act in direct opposition to each other. In speaking of the mechanical powers, we considered the weight and power as acting directly: we are now to consider in what case the equilibrium is produced when they act obliquely. Let there be a balance AB, & the weights C&D in equilibrio. If the power at D be exerted in the oblique direction BE, its loſs of intensity will be represented by the horizontal line DE, and will be as the sine of the angle DBE, or cosine of BED. The equilibrium takes place when the power is to the weight as radius to the sine of the angle of obliquity, viz. when D:C:: BE: BD. — Hence it appears, that the greater the ratio of DE to DB, the greater will be the force lost; i.e. the proportion of force lost increases with the obliquity of the action. It deserves here to be mentioned, that we lose in the composition and gain in the resolution of forces.

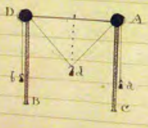




In compounding the two forces AB & AC into the diagonal AD, we evidently lose, because the latter is leſs than the two former. For the same reason we gain in resolving AD into AB and AC.

In a bended lever, the intensity of the power is to be estimated by the perpendicular let fall from the fulcrum on the direction in which it acts. Let ABC be a lever having the arm BC horizontal, and AB inclined. The intensity of the power applied at A will be expressed by the perpendicular DB drawn upon its direction AD, from the centre of motion B. In all cases the power and weight balance each other, when they are inversely as the perpendiculars let fall from the fulcrum on their respective directions.

If three powers acting in oblique directions be to one another as the respective sides of a triangle formed by the concourse of three lines drawn parallel to the directions of the powers these powers will balance each other. For instance, if three powers drawing the point A in the directions AB, AC and AE, be to one another as the sides of a triangle ADC, or ADE, made by the concourse of the lines AD, AE & ED, or AD, CD, & AC; which lines are parallel to the directions of the powers — they will balance each other and the point A remain unmoved. Let CD be parallel to AE; then CD will represent the force acting in the direction AE; let BA be continued in the direction AD, and let three sides AC, CD, & DA be one another as 2. 3. 4. If then, a line be stretched over BA, over AC, and over AE — (which is the same as CD); and if to the first be hung 4oz. to the second 3. & to the third 2, they will be in equilibrio. the proposition may, by aid of the above figure, be made clear without the aid of experiment. See Helsham! When weights are raised directly up, the loss of force is in proportion to the obliquity of the direction of the power. If the perpendicular force be resolved into two others, the sine of the oblique angle will express the loss of force. —— Let there be two stands DB and AC with a pulley over each of their heads A & D. Let a cord bDdAa go over each of the pulleys. Let 1oz. be suspended at b, another at a, and a third at d. Owing to the obliquity of the action, the two a & b, will raise but a very little way the remaining one d; add another ounce at b & a, and they will raise d a little



higher, for instance to the second point; increase a & b by adding another oz. d will be raised to the third point, a distance from the second leſs than from the second to the first.– continue to increase a & b, and you continue to raise d, but every time a leſs distance. the reason is, that the action of a & b becomes more and more oblique; and universally, the power will diminish in its force, and in its effect, in proportion to the obliquity of the direction in which it acts.—

2nd Of Friction.

Friction is the resistance which bodies meet with in moving over the surfaces of each other. No bodies can be so perfectly polished, but that they will have numberleſs little cavities and protuberances. Hence, when one body paſses over another, its protuberances sink into the cavities of that other, and the protuberances of the latter into the cavities of the former. this is the true cause of friction. Were a body perfectly smooth, still there would be some little friction arising from the principle of cohesion. See Ex. P. that friction is not owing to the weight of bodies, but to the eminencies of one sinking into the cavities of another, is evident from observing, that those which have the smallest cavities, have the least friction. Hence a canoe is with difficulty dragged over the ground, but easily overcomes the resistance of the water; whereas the resistance would be the same in either case, if it depended only on the weight of the body.—

Friction is considered of two kinds. 1. When the same parts of the moving body are made to touch succeſsively different parts of the body over which it moves. 2. When the moving body continually presents different surfaces to the body on which it moves. The first kind may be illustrated by the sliding of a book over a table. the second by the rolling of a ball along a plane.

The quantity of friction depends on a variety of circumstances.– 1. the nature of the surfaces. 2. the quantity or size of the paſsing surface. 3. the preſsure. 4. the velocity. 1st The nature of the surfaces is a material consideration. the more prominent or more rigid the surface is, the greater will be the friction. the reason is, that in rough surfaces the protuberances are more eminent, and the cavities deeper, than in smooth ones; and from these causes friction arises. It must therefore be sensibly affected by the surfaces.

Oil serves to fill up the cavities of surfaces, and, of course, diminishes friction. Its effect is greater on wood, than on metals. Water has a contrary tendency from oil, on many bodies. For example, it will increase the friction on wood. We may account for this in the following manner— Water is known to enter into the pores of wood, & swell it. Of course its protuberances will be thereby enlarged.

Friction does not depend upon the quantity of surface, for it will require the same force to draw a smooth piece of wood on the broad as the narrow side, on another equally smooth. Altho' on the broad side there be 4 times the number of touching particles, yet each particle is touched with but $\frac{1}{4}$ part of the weight of those on the narrow side; and since 4 times the number multiplied by $\frac{1}{4}$ part of the weight is equal to $\frac{1}{4}$ the number multiplied by 4 times the weight, 'tis the effect, that is, the resistance, is the same in both cases, and will require the same force to overcome it — We must observe, that some late experiments, made very accurately, seem to contradict the above position. Bishop Madison says, if a flat body be caused to slide over a surface, the friction will be greater edgewise, because the touching parts bear so much more weight.

That friction is in general nearly equal to $\frac{1}{3}$ of the weight of the body, may be shewn by the following experiment. If a body be placed upon a board 18 inches long, it will not slide down until the board has attained an elevation of 6 inches, that is $\frac{1}{3}$ of its height.

Friction is increased by pressure, but is not in direct proportion to it.

Some writers contend that friction is increased by velocity on account of more protuberances being passed over in the same time. But it has been found by late experiments, made chiefly by M. Coulomb, that friction for the most part is not augmented by an increase of velocity. In some cases, indeed it is diminished. When the touching surfaces were very small in respect to the force with which they were pressed, the friction was diminished by augmenting the rapidity: on the contrary it was increased when the surfaces were very large when compared with the force of pression.

In sledges the friction is equal to $\frac{1}{3}$ of the weight; in carts to $\frac{1}{30}$, the diameter of the wheel being 6 feet, that of the axle

4 inches. To estimate the quantity of friction of any body of the same weight and nature, let the rubbing parts be multiplied into the velocity. Friction is leſs in diſsimilar bodies, because, as the protuberances and cavities are not likely to fit, they will stand upon each other, and occasion leſs resistance. The heat attending friction, is produced by the tremulous motion of the substance rubbed, and is prevented by stopping this tremulous motion

Wheel Carriages.

We shall pursue still farther the science of mechanics which has rendered such infinite advantages to mankind, particularly in the construction of wheel carriages. Deprive a nation of these inestimable bleſsings, and what will be the consequence? Deprived of the means of conveying with facility, their commodities from one place to another, and of keeping up that mutual intercourse so neceſsary to their welfare and happineſs, all things would be immediately thrown into confusion. This consideration sufficiently evinces the importance of the present subject. It has accordingly attracted the attention and diligence of philosophers.

Wheel carriages were invented to avoid, as much as poſsible, the effects of friction, and thereby facilitate the conveyance of goods by land. The rotation of a wheel upon its axis is caused by friction which occasions a resistance to one part of the wheel while the other is at liberty to move with perfect freedom; but the latter not being permitted, by the cohesion of the parts of the wheel, to move on by itself, must move, of course with the former, and a rotatory motion ensues.

The advantage of wheels over sledges is very great. In the latter, the inequalities of the ground afford so many obstacles to the moving body, which must be overcome by the force applied to draw it; but these obstacles afford an oblique opposition to wheels, which is much easier overcome than a direct one, and the more so in proportion to the largeneſs of the diameter.

The observations on the subject of this lecture, may be comprised in the four following propositions.—

1st Large wheels are more advantageous than small ones. Let there be a carriage drawn on 4 wheels. see what power is neceſsary to draw it, change the wheels to a smaller set, and more weight will be required to draw it, than in the former case. Large wheels do not sink so deep into hollows as small ones, and even when they sink equally deep, the largest will be easier drawn out because the power acts higher above the impediment. the friction between the surface of the rims, and the ground is diminished in proportion to the largeness of the wheel in diameter. That on the axle is diminished in the ratio of the circumference of the wheel to that of the axle. the advantage of large wheels when moving on a plane, is as the square root of the radii of the wheels.—

2nd A carriage with four wheels of equal size, is drawn with less force than one with two large and two small. This may be made clear by experiment— Small wheels are used for the greater facility of turning, & to avoid cutting the braces, as well as, rubbing against the braces. Some have supposed that large wheels push on the small ones. the idea, says Ferguson, is too absurd and unphilosophical to be refuted. In going up hill, however, there must be some advantage in having the wheels before smaller than those behind, because the body of the carriage will then move upon a level, & therefore be more easily drawn. When going upon a horizontal plane, the load should be placed behind, but in common roads, in the middle, or equally spread all over the carriage, and not on the fore wheels, as is too common. the height of the wheels should be regulated by the nature of the power which is to draw the carriage— Their axis should be precisely in a line with the horse's breast, which may be easily comprehended by any one who understands the doctrine of the composition and resolution of forces.

3rd Carriages with 4 wheels are more advantageous than those with 2.— If the fore wheels of a waggon sink into the mud, half the weight only is to be drawn out. But if the two wheels of a cart sink into the mud, the whole weight is to be drawn out. Desagulier's estimate is, that 4 horses in a waggon are equal to 6 in a cart.—

4th Broad wheels are more advantageous than narrow— Because they do not sink so deep into the ground. Narrow wheels may be considered as constantly going up hill. In clayey roads, however, the broad wheels clog too much— Another advantage they have, which is, that they make the roads better, instead of cutting them into ruts. the wheels of a carriage should be made dishing. Wood is strongest in a perpendicular situation, and when the carriage is aslant, the spoke from being dishing, is perpendicular. It is extremely advantageous that the carriage should be fixed on springs. 1. When the wheels come to an obstacle, the carriage fixed on springs jolts forward, and thus assists in surmounting it; 2 the springs raise the centre of gravity. Now the nearer the centre of gravity is to the obstacle to be overcome, the greater will be the resistance of that obstacle, and vice versa.

We must observe in regard to the 3rd proposition that a carriage with two wheels is preferable to one with 4, as to friction. A late writer says, that on a level turnpike, a horse in a cart will draw 25 Cwt; whereas in a waggon, & on fine roads, it would require 6 horses to draw 90 Cwt.

We shall conclude with a few remarks on the comparative strength of men and horses. One horse with another will be found to draw 200 lbs for 8 hours in the day— In mills, where a horse has to draw in a circle, great care should be taken to let him draw in a tangent. If the circumference of the circle be small, he will labour to great disadvantage. It should therefore be not less than 110 feet in diameter. 5 men by the English are reckoned equal to one horse; the French say 7— Hence the English infer that 5 Englishmen are equal to 7 Frenchmen. A horse exerts most force, & a man the least, horizontally. A man will climb faster up a steep ascent with 1 cwt, than a horse with 3 cwt. By an advantageous position, a man could support a cannon of 4,000 lbs weight. There has been an instance of a person placing his head on one chair, his feet on another, and having an anvil on his breast; so that by hammering on it ever so hard, you could not hurt him. As to the maximum of the strength of animals, it appears to be a law of nature, that the smaller the animal, the greater its strength in proportion to its size. The largeness of an animal might be so increased, as utterly to annihilate its strength— It is a curious circumstance, that hollow bodies, as hollow spears, are much stronger than solid ones. Hence the bones of all animals are made hollow.

Additional Observations.

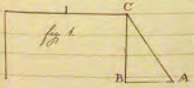


fig 1.

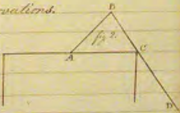
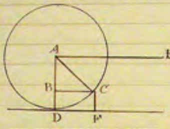


fig 2.

The length of lever lost from obliquity of action, will be as the sine of the angle BCA (fig 1), or it will be in the ratio of AC to AB (fig 2) AB being the perpendicular let fall from the fulcrum on the oblique direction BD. —— The friction on large & small axles, will be inversely as their size. Thus if 1 axle be twice as large as another the friction on the latter will be twice as great as on the former. — If a wheel acts as a lever, it can only be in overcoming the resistance upon the axle. — The advantage of large wheels over small was as 17 to 12 when their size was as 2 to 1.



Small wheels are advantageous in going over obstacles because the line of traction is lower than the horse's breast.

M. Deparcieux has shown very satisfactorily, that animals draw by their weight, and not by the force of their muscles. the force of the muscles tends only to make the horse carry continually forward his centre of gravity, or in other words, the weight of the animal produces the draught, & the play and force of his muscles serve to continue it. In four-footed animals the hindfeet is the fulcrum of the lever by which their weight acts against the load, & when the animal pulls hard, it depresses its chest, & thus increases the lever of its weight, and diminishes the lever by which the load resists its efforts. ——

Lecture XIII.

Electricity.

The earliest discovery in this branch of natural philosophy, which is recorded in the history of sciences, was made by Theophrastus a Grecian. After him, fifteen hundred years elapsed, before any farther improvement took place. In 1600 Dr. Gilbert published a treatise in which he gave an account of several electrical experiments. Theophrastus had observed the amber and the lyncurium has the property of attracting and repelling light substances; but Dr. Gilbert discovered that this property was common to many other substances as well as amber. After Gilbert, the science made slow and gradual advances. It attracted the attention of Bacon, Boyle, Otto Guerick, Newton and particularly Mr. Hawksbly. He first discovered the electrical power of glaſs. After Mr. Hawksby, the science remained 20 years in a state of quiescence; Sir I. Newton's new and important discoveries about that time engroſsing the whole attention of the learned. At length Mr. Gray again rescued it from darkneſs. Since his time many great men have bestowed on it their attention; among them Franklin deserves the highest rank. This great man was no leſs conspicuous for his attachment to the rights of man, than for the genius he poſseſsed of investigating natural causes, and of observing the phenomena of the natural world. Eripuit cœlo fulmen sceptrumque tyrannis.

The amusement which electricity affords us, is alone a sufficient inducement to study it. The cultivation of this science cannot fail to be particularly grateful to the inquisitive mind of man. Its peculiar advantage is, that it may be carried on as a recreation. I therefore advise my student to furnish himself with an electrical machine, and more especially, since the expense is small compared with the pleasure it will afford. He may then make discoveries of his own; and every one must be sensible that the satisfaction we feel from our own experiments is far superior to that which we derive from the discoveries of others. — There is no truth of which I am more convinced than this, that throughout life, human happineſs depends upon having some laudable object to pursue, and on exerting our faculties with sufficient energy in the pursuit of it. A proper object is presented to us in the view and investigation of the works of nature, among which the electrical properties are not the least worthy of our attention.

The term electricity is derived from a greek word which signifies amber, because that body was for a long time supposed to be the only one poſseſsed of the electrical properties. The word is not always used correctly; for it is sometimes taken for the cause, and at others for the effect. Electricity is the property which some bodies have of attracting and repelling light substances, of shining in the dark, causing a pungent sensation &c. The electric matter is equally diffused throughout all bodies of nature. The quantity of it inherent in a body is called the natural quantity of that body. When a body poſseſses more or leſs than its natural quantity, the equilibrium is disturbed, and the electricity disengages itself. The method of distinguishing this equilibrium is principally by rubbing. Thus, by rubbing a tube of glaſs you may perceive electrical effects, and a snapping noise will be heard. The same effect may be produced by sealing wax, baked wood, and many other bodies. If the experiment be made with the glaſs tube in the night, it will appear quite lucid. The attraction, repulsion &c. observed in electrical experiments, are called electrical appearances. When a body is made to exhibit them, it is said to be excited. In that situation it must be considered as poſseſsing more than its natural quantity. All bodies capable of being excited are called electrics. A machine capable of exciting an electric, is called an electrical machine. A contrivance to determine the quantity of electricity produced, is called the electrometer. The body applied to the electric to excite it by means of friction, is called the rubber.

The electrical equilibrium would never be distinguished unleſs from this particular circumstance, that some bodies do not admit the electric fluid thro' their pores, while others do. On account of these properties, the former have been called non conductors, and the latter conductors. Experiment. Touch the prime conductor with a piece of glaſs and it will not prevent the sparks from flying; which proves it to be a non conductor — Touch it with a piece of metal and it will be found to prevent them. This proves that metal is a conductor. — Silk is a nonconductor, baked wood a nonconductor, paste a conductor, and paper a non conductor. A body resting entirely upon non conductors, is said to be insulated. In that state the body is capable of retaining the electric fluid, which cannot poſsibly escape.

The first and principle maxim in electricity is, the division of bodies into conductors and non conductors. It is impoſsible we can make any progreſs in electricity, without a knowledge of this particular. Non electrics are those bodies which cannot be made to exhibit electrical appearances, and we have said that electrics are those which may be excited. Conductors are not capable of being excited. Electrics do not conduct. Hence conductors are non electrics, electrics and non conductors have been considered as synonomous. This division however, is not strictly just; for no body in nature is a perfect electric; none a perfect conductor. It has been supposed that every body in nature poſseſsed its share of electricity: hence the terms conductor and non conductor are preferred to electric and non electric.— Any contrivance which may excite an electric is termed an electrical machine. Whatever receives the electricity there excited, is termed a prime conductor; which is said to be insulated when it rests entirely upon non conductors. The bodies belonging to the claſses of conductors and non conductors follow in the order of their perfection. **Conductors.** Gold, silver, copper, platina, braſs, iron, quicksilver, lead, semi-metals, ores, charcoal, animal fluids, all fluids air and oil excepted, the effluvia of flaming bodies, ice, snow, saline substances, several stony do, smoke, the vapour of hot water. The different degrees of perfection of these conductors vary extremely according to their temperature. Wood exhibits a most curious phenomenon. When green it is a conductor; when baked a non conductor; when reduced to a charcoal a conductor, and a non conductor when reduced to ashes. **Electrics.** Glaſs and all vitrifications, precious stones of which the most transparent are the best. amber, sulphur, baked wood, resinous substances, wax, silk, cotton, all dry animal substances, paper, white sugar, sugar candy, air, oils, calces of metals and semi metals; the ashes of animal and vegetable substances, all dry vegetable substances, all very hard stones. Heat has the effect of rendering some of these electrics good conductors. They should be perfectly dry, or they will be troublesome to excite.

Of the different methods of exciting electrics.—

The first and most obvious method of exciting electrics is by rubbing. The friction disturbs their natural quantity. Many other methods have been employed for the purpose of excitation such as melting, evaporation, heating, cooling &c. Electrics will exhibit electrical appearances when rubbed. The rubber then is a material point to be considered. It should be a conductor. It is commonly made of leather and covered with an amalgam made of moving and sink, a tie of such cannot be perceived. The manner in which the electric fluid is excited is a subject of curious speculation. As yet, it rests upon the uncertain foundation of conjecture. Dr. Franklin supposes that the electrical fluid is contained in the pores of the electric, that by friction these pores are opened, and that in closing again they push out the electricity; that the points presented by the prime conductor take it off and accumulate it thereon; it being unable to pass off owing to the insulated condition of the prime conductor. This hypothesis, however, applies only to the excitation produced by rubbing, and is on that account insufficient. Again, it has been supposed that the electricity lays on the surface of the electric in the manner of fine sand; and that it is by friction collected into one part of the body, or rather of its surface. This hypothesis is insufficient for two reasons. 1. For the one objected against Dr. Franklin's. 2. If it were true, one would imagine that in rubbing an electric, what was gained in rubbing it one way, was destroyed, or replaced in its natural situation by rubbing it the other: No electrical appearances would therefore be exhibited: — the contrary of which takes place. It is certain, however, that the electricity is not created by friction; for if the rubber be perfectly insulated, none can be collected. Connect the rubber with the general mass and some is immediately collected: the electricity, therefore, is extracted from that general mass. It appears also, that electricity is the effect of matter in motion. We can see it, hear, feel, smell, and taste it: it makes holes if any yielding body oppose its passage: it melts the hardest metals, and burns inflammable bodies. —

Of the electric spark; and of communicated electricity

The electric fluid may be accumulated on a body and there confined. If the air be very dry, it will be retained for 12 and 24 hours; and was there no conducting substance it would be retained forever. The spark follows the shortest course and best conductor. It will prefer a long course and a good conductor, to a short course and a bad one. When an electric is excited, it parts not with all its electricity at once; because it cannot conduct the electricity to the touching point. Were there a perfect conductor with electricity accumulated on it, the fluid might be all taken off at once. But there is no perfect conductor; therefore even the best conductors do not lose all their electricity at once. If an insulated conductor touch an electrified body, it will exhibit electrical appearances. If for instance, a person standing on a cake of wax, or on a stool with glaſs feet, touches the prime conductor, sparks may be taken from him.

.... If on wax some fearleſs beauty stand
And touch the sparkling rod with graceful hand:
Thro' her fine limbs the mimic lightnings dart,
And flames innocuous eddy round her heart,
On her fair brow the kindling lustres glare
Blue rays diverging from her brilliant hair,
While some fond youth the kiſs ethereal sips
And soft fires iſsue from their meeting lips. Darwin.

Similar surfaces will acquire equal quantities of electricity, the larger surface more than a smaller one: the smooth surface more than the rough. The electric spark is always accompanied with a crackling noise, because, we presume, of the resistance it meets with in paſsing thro' the atmosphere. It takes an angular direction. The irregular situation of the watery particles of the air thro' which it is conducted, produces that direction.

Lecture XIV.

Of the two electricities; or of the different manners in which bodies may be electrified.

Let there be two persons insulated, one whereof communicates with the rubber insulated, and the other with the prime conductor. Both these persons will be electrified. Their electricities, however, will be very different. One will be directly the contrary of the other. If any person touches him who communicates with the rubber, electricity will appear to pass from the former to the latter. If he touches the person who communicates with the prime conductor, electricity passes from the latter to the former: as if one were undercharged and the other were overcharged.

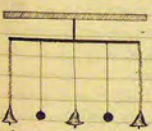
The following is a general law concerning the electrical fluid, viz. that it consists of particles which tho' attractive of other bodies, are strongly repulsive of each other. Present an insulated light substance to either the person who communicates with the prime conductor, or to him who communicates with the rubber: it will, in either case, be strongly attracted at first, but will presently be repelled, and after being repelled, will not be attracted again. This experiment proves, that when an electrified body communicates its electricity to any other body, both thereby receiving electricity of the same kind they repel each other; and the fact proves the repulsive quality of the electrical fluid.

If a wire, (or a pointed body) be presented to the prime conductor, a lucid globule will appear upon the point of the wire. If it be presented to the insulated person touching the rubber, a lucid pencil of rays will be observed, diverging to the person. This will be most conspicuous in the dark. Julius Cesar, in his commentaries, mentions that a globule of the description just given, settled upon the points of the soldier's spears.

These two different electricities are distinguished by the terms positive and negative electricity. That which is exhibited on the prime conductor is termed positive; that exhibited by the person touching the rubber is termed negative. They are also termed, the one plus, and the other resinous: and because the first is always exhibited by excited glaſs it is called vitreous; and because the last is produced by excited wax, or other resin, it is termed resinous electricity. The same bodies may be made to exhibit different electricities by means of different rubbers; and the same rubber may excite in different bodies the same electricity.

If two bodies are rubbed together, that which is the best electric acquires the positive, the other the negative electricity. If their degree of smoothneſs be different, the smoother will acquire positive, the rougher negative electricity; or perhaps a compound of these principles may afford the best general rule: — yet this rule will not always hold. See Cavallo— .

There are two laws respecting electrical attraction and repulsion. the first respects the quality of repulsion in the electric fluid, and has been already mentioned. The second is, that similar electricities repel and diſsimilar attract. Let two insulated balls be either negatively or positively electrified: they will repel each other. Let one be electrified positively, the other negatively: they will attract each other, and afterwards show no signs of electricity: that which was positive, it seems, discharging its surplus into the exhausted receptacles of the other .. — Let there be a metalic bar suspended to the prime conductor, to which are fixed three bells and two metalic balls: the two outer bells suspended by chains; the balls and middle bell by silk strings; and let a wire connect the middle bell with the earth. Let the machine be then put in motion, and the bells will quickly begin to ring. The reason is this: the two outer bells become electrified: they therefore attract the balls: these become then electrified also, and are repelled, and in their turn attract the middle bell, to which they communicate their surplus of electricity: the wire carries this surplus off: the balls are again attracted by the outer bells; again are repelled: again attract the middle bell; again communicate to it the surplus of electricity it has acquired, which is carried off by the wire as before.



Former electricians observing how different substances, such as glaſs and resin, produced different electricities, thought that there was a real difference in their natures. Dr Franklin was of opinion, that there is but one kind of electricity, and that the phenomena exhibited by bodies differently electrified result from an undercharge in the one case, and an overcharge in the other;

or, which is the same thing, that a body is positively electrified when it has more than its natural quantity, and negatively when it has less. This theory is ingenious; it is probable, it is worthy of Dr. Franklin. There is but one fact which opposes it, all the other phenomena being favorable to it. But this is, indeed, a stubborn fact. We can readily conceive, that the repulsive quality of the electrical fluid will necessarily produce a repulsion between two substances positively electrified. We can conceive that (on account of the known principle of fluids, that they tend to preserve an equilibrium, and endeavour to restore it when disturbed) the body electrified positively will attract the body electrified negatively. But why do two negatively charged bodies repel each other? Can the repulsive property of electricity operate to produce this effect?... One would naturally suppose, that as two bodies with precisely their natural quantity are indifferent to each other; much more would two with less than their natural quantity be indifferent to each other. Cavallo attempts to solve this difference. Whether his argument be clear or conclusive, I shall not undertake to determine. I do not comprehend its force. Dr. M. accounts for it in this way. When a body is negatively electrified, he supposes it to be surrounded with a corona, or kind of atmosphere of its own, which is positively electrified. There is a repulsion between these positive coronas, and hence the two negative electricities repel. He mentioned an experiment he had made to confirm it. He did not own himself to be satisfied with the result. — Without any experimental proof either for or against this hypothesis, it will not bear investigation. Grant that the bodies negatively electrified, have their positively electrified coronas. Grant that the coronas cause their repulsion. It is just to suppose that those bodies which are positively electrified, have their negative coronas. Let me ask, then, why these negative coronas repel each other? Which is the same thing as to ask why the negative electricities repel. The difficulty, therefore, is yet unsolved.

Of Points.

If you present a point to the prime conductor, the electricity will be silently drawn off by it, and in small quantities at a time. — If you present a nob, the electricity will be drawn off in greater quantities at a time, and with a noise. The former is the more gentle, the latter the more violent method. —

Lecture XV.

Of Electricity communicated to electrics.

If an insulated conductor be brought near an electrified one, the following remarkable phenomenon will take place. The end adjacent to the electrified conductor will acquire an electricity contrary to, and the end more remote the same with, that of the conductor. If however, the insulated conductor be brought within striking distance of the other, it will immediately receive in every part the same electricity as that of the electrified conductor. If an electric, a glaſs tube for instance, be brought near an electrified conductor (say positively) the end next to the conductor will also be electrified positively for an inch or two; it will then for the same space be electrified negatively; then positively, and so alternately becoming every time weaker and weaker 'till it entirely vanishes.— These remarkable phenomena can be accounted for only upon the following general law; that bodies adjacent to an electrified body are apt to acquire an electricity contrary to that of the electrified body. This accordingly has been laid down as a general law. Thus if a body be insulated at a considerable distance from other conductors, & show signs of electricity upon its surface, the air is supposed to acquire the contrary electricity. The air not being a perfect electric, easily acquires a contrary electricity on a stratum of its substance, that is, at a little distance from the electrified body, and in consequence of this stratum, it acquires another stratum contrarily electrified and a little distance from the former: to this other strata succeed alternately poſseſsed of positive and negative electricities, and decreasing in power until they vanish or come to the walls of the room &c.—

When one side of a body is positive and the other negative, it is said to be charged. When the equilibrium is restored, it is said to be discharged. If one side of an electric be presented to an electrified body, that side will immediately receive the kind of electricity it contains, while the opposite side, if it communicate with conductors, loses an equal quantity, and becomes differently electrified. In order to prove this, let two electrometers be fixed, one on the side communicating with the general maſs, the other on the side presented to the prime conductor. Let the electric be charged. Both electrometers will appear affected by the electricity. Present a stick of excited sealing wax to the electrometers: one will be attracted by it, the other repelled. The electricity of the sealing wax is negative; now negative electricity repels negative and attracts positive. One side therefore of the electric is positive, the other negative. Moreover, if the electric be insulated, so that one side cannot lose its electricity as the other acquires it, it cannot be charged at all.—

The electric most commonly used is glaſs. Owing to its non-conducting quality (and its tenacity in retaining the electricity when electrified) the electricity can with difficulty be diffused over its surface. It is therefore coated with some conducting substance; tin foil, for instance. This coating should not be placed too near the edge of the glaſs, for the electricity may discharge itself. A repulsive power is certainly excited through the glaſs, which, therefore, should be thin. If it be thick, it cannot be charged at all. To what degree of thickneſs the repulsive power may act, has not yet been determined. When the electricity wishes to restore the equilibrium, it meets with some resistance; which causes the explosion or spark. If this spark paſs thro' the human body, it causes a disagreeable sensation which is called a shock. When an electric is charged, it cannot be discharged unleſs some communication be formed between its positive and negative sides. If the glaſs be very thin, it is apt to be broken by the strong attraction of the two different electricities, which affect its sides. The power of giving the shock resides only in the glaſs, not in the coating.— Let a piece of glaſs with loose coating be charged: let the coating be thrown off, and it must neceſsarily lose all its electricity. Let it be again put upon the glaſs: the glaſs, it will be found, is capable of giving the shock.

The Leyden phial is only a bottle coated on the inside and outside in order to be charged: it is the same thing as a coated pane of glaſs in a different shape. As one side of the coating becomes positively electrified, the other loses just as much, and becomes negatively electrified. The coating should not be too near the mouth for the same reason that it should not be too near the edge of the pane of glaſs. The reason that a heated electric cannot be charged is, that it is a conductor: the electricity is continually conducted to the edge where it restores the equilibrium.

A phial may be charged in various ways, as the following problems will shew. We will premise that the electrometer shews when the bottle is charged, for it will immediately rise. Problem 1st. To charge a bottle by its own electricity. Let the rubber be insulated. Let the bottle be suspended by a wire which communicates with its inside.—

Let a wire be tied around the outside, and be made to communicate with the insulated rubber. In this case the rubber can extract no electricity from the general maſs. When the machine is put in motion, the inside becomes positively electrified. The electricity leaves the outside of the bottle, paſses thro' the wire to the rubber; from thence is accumulated on the prime conductor, whence it is collected into the bottle. Problem 2d. To charge a bottle positively on the inside, and negatively on the outside. Present the wire communicating with the inside to the prime conductor. The inside becomes positively electrified, and expels the electricity from the outside, provided that the outside be connected with the general maſs. This is the most usual way of charging a bottle. Problem 3d. To charge a bottle positively on the outside, and negatively on the inside. Place the outside coating on the prime conductor. The wire communicating with the inside must be connected with the general maſs by some conducting substance, the human body for instance. The outside becomes positively electrified and expels the electricity from the inside. Problem 4th. To charge air. Suspend a plate by the prime conductor, place under it another insulated: the intermediate air will be electrified. The circuit which the electric fluid takes in order to restore an equilibrium, is always through the best conductor, and shortest route. It will prefer a long good conductor to a short bad one as we have already observed. But if there be a number of conductors equally good, it will divide itself equally amongst them. The velocity of its paſsage is inconceivable. It has been found to travel many miles in an imperceptible space of time. The force of the shock is diminished by the length it goes. The force of the shock depends upon the quantity of electricity, the conductor, and the point from which it flies. The greatest force of electricity is exhibited by a battery. This is so constructed as to unite the power of many jars. In this manner a shock may be given which is made up of the combined force of the whole. There is a battery in the apparatus of Wm & Mary sufficiently strong to take away life.

Lecture XVI.

Of the effects of electricity upon plants and vegetables. Of medical, animal, magnetic, and atmospherical electricity.

Part 1st. Of the effect of electricity upon vegetables. Some have supposed that a vegetable kept in a state of positive electricity generally had its growth quickened thereby; and that to keep it in a state of negative electricity produced the contrary effect, of retarding its growth. It has been thought by some that a spark produces the former effect: on the other hand, it has been thought to destroy the vegetable entirely. But late experiments have proved that it has no effect either one way or the other. A violent shock destroys both animal and vegetable life.

Part 2. Of medical electricity. In the early stages of this science, it was regarded as a panacea or cure all. The general application of it to every disease; the imaginary cures attributed to it; the real mischief it produced by being used either in improper cases or in an improper manner; and the remarkable inconstancy of its effects; after a while brought the practice of medical electricity into ridicule and disrepute. Some physicians afterwards, by a judicious use of it, retrieved its character. Cavallo has made many observations upon the subject, and mentions many cases of its use and beneficial effects. It acts in three ways as a sedative, a stimulus, and a   The disorders in which it has been found most useful, are the following. Rheumatic disorders — draw off the electricity by a wooden point thro' flannel — Deafness — Draw off the electricity to the ear by a wooden point — Toothache — Draw off the electricity in the same manner — Swellings containing no matter — The same manner of application. Inflammations of all sorts, of the eyes &c. In inflammations of the eyes, the operation should be as gentle as possible in order to prevent irritation: a metalic instead of a wooden point must always be used. Gutta serena — Use first a wooden point, and then a series of gentle shocks. The Fistula lacrymalis — use a wooden point. Palsies. — Use the wooden point, or draw sparks thro' flannel from the parts effected. Ulcers, cutaneous eruptions, scrophulous tumors, cancers — Use the wooden point. Absceſses — The electricity to be sent thro' the parts affected by means of two Dropsy. the same mode of application. Pulmonary inflammations — Gentle shocks. Nervous headachs & the gout Use the wooden point. Agues — Draw sparks thro' flannel. Some other diseases are mentioned in which electricity is beneficial. Whenever metalic points fail in producing the desired effect, wooden ones must be resorted to. They draw off the fluid in larger quantities, and more violently than those of metal. If wooden points also fail, shocks must next be used. They must be very gentle, begining with those of an inch square of coating, and increasing gradually as neceſsity may require.

Electricity promotes perspiration, pulsation, and secretion. It must carefully be avoided in cases of pregnancy. There are many methods of applying electricity. Formerly large shocks were used: now, when shocks are used at all, they are very moderate. There is a method of giving small, regular, periodical, shocks. The mode mentioned above of drawing off, and throwing on electricity by means of points, is now most generally used. The patient is placed upon an insulated stool, and connected by a conductor with the prime conductor. Electricity is thus accumulated in him without the poſsibility of escaping: apply then a point to the part affected, which will draw off the electricity and produce a sensation like that of a very gentle wind blowing on the part. It may either be drawn off, or thrown on. To throw it on, let a wire be fixed to a prime conductor; let the other end be wrapped round a glaſs tube; let a person holding the tube, apply the point of the wire to the patient standing conveniently: and the electricity may be thus thrown on. there are grades in the violence of the application of electricity.

Part 3. Of animal electricity. It has been found that some animals are capable of giving a sensation similar to the electrical shock. This property is called animal electricity. The torpedo, the gymnotus electricus, and the silurus electricus, are found to poſseſs it. It is remarkable that these fishes cannot affect any bodies which are non conductors of electricity. As soon as a conductor is brought near to them, they will approach and give the shock. the shock is greater if both sides of the fish be touched at once. The ancients thought this shock beneficial to patients in some diseases. Why the animal is endowed with this power, we know not, unleſs for the purpose of securing its prey, and of defending itself against the attacks of other animals. It has been discovered that the sides of those fishes are in columns, similar to an electric battery.

Part 4. Of magnetic electricity. It has been found that the ordinary effects of electricity do not interfere with magnetism; for a magnet placed upon a prime conductor will continue to play freely. A strong shock, however, will reverse the poles of a magnetic needle, or render a common needle magnetic. The end in which the shock enters, always points north. Dr. Madison thinks that this effect of a shock arises from the blow it gives the metal, not from the power of electricity. The explanation of other phenomena, hereafter to be mentioned, requires that this idea should be relinquished. —

Part 5. Of atmospherical electricity. The most important discoveries in electricity are to be mentioned under this head. It has been long believed that electricity and lightning were the same; but it never was positively asserted until Dr. Franklin undertook to prove the fact. The following analogies led to the conjecture of their identity. 1. A stroke of lightning is always attended by a flash of light: so is electricity. 2. Lightning is conducted by the same substances as electricity. 3. It strikes at the best and nearest conductor: so does electricity. 4. It takes a zig zag direction: so does electricity. 5. It has a sulphurous smell: so hath electricity. 6. It fires certain substances: so doth electricity. 7. It melts metals: so doth electricity. 8. It reverses the magnet: so doth electricity. 9. It destroys animal and vegetable life: so doth electricity. 10. Their colours are also similar; and all the phenomena of the one may be represented in miniature by the other. These facts led to the almost certain conjecture of their identity. But Dr. Franklin would be contented only with absolute fact. He published his opinion and the mode he intended to adopt to prove it. The French philosophers, with their usual diligence in the pursuit of truth, a month before Dr. Franklin brought down the lightning from the clouds by means of the electrical kite. Experiments have actually been made, both by them and Dr. Franklin with the lightning thus procured; which proved it the same with electricity. The kite is of simple formation. The sparks got by the French electricians were remarkably large, and might be heard a hundred yards: sometimes with an explosion like thunder. Dr. Richman was struck dead by a spark which he received from his metalic spire, by some imprudence in his management.

The clouds are generally electrified either positively or negatively. How they come so is a question of which, as yet, there is no rational solution. Thunder is supposed to be the effect of electricity rushing to restore the equilibrium from a positive to a negative cloud; sometimes from a positively electrified cloud, to a part of the earth electrified negatively; sometimes from a part of the earth electrified positively, to a cloud charged negatively. It may be determined whether it strikes up or down by the splinters it makes upon the houses or trees which it strikes. The earth is frequently a conductor between two clouds, when they are very low and at a great distance apart.

Rain, hail, snow, vapour &c. all poſseſs a share of electricity. I will lay down the following general laws respecting atmospheric electricity. 1. There is in the air at all times, a greater or smaller portion of electricity. 2. The electricity of the atmosphere, fogs &c. is almost always of the same kind, and negative. (Cavallo says positive.) 3. The strongest electricity is observed in frosty and wet weather, &c. at night, and on eminences, tho' the reason is not very apparent. Lightning is always greater and more frequent in summer than in winter. It is accounted for in this way). The heat of summer renders it neceſsary for the vapours of which the clouds are constituted, to ascend higher in order to find a region sufficiently cold to condense it. This circumstance causes the clouds to be so much elevated above the earth, that the electricity cannot discharge itself, except when a large quantity of it is collected together. Consequently its explosion is louder and more distinctly heard. In winter the weather being cold, the vapour finds a condensing medium near the earth, and owing to the contiguity of the clouds to the earth, it is attracted and carried off in such small quantities, that the phenomena are not perceivable.

Of Meteors.

There seem to be three concentric strata of our incumbent atmosphere, in which or between them, are produced four kinds of meteors, viz lightning, shooting stars, fire balls and northern lights.—

First, the lower region of air, which is dense enough to resist the descent of the condensed vapour, or clouds, and may extend from one to three or four miles. In this region the common lightning is produced from the accumulation or defect of electric matter in those floating fields of vapour. As lightning is produced in a dense air, its course is short; and on account of the resistance of the atmosphere, it is attended with a loud explosion, and appears with a red light.

The second region is that which has too little tenacity or density to support condensed vapour or clouds; but which contains invisible vapour or water in aerial solution. This aerial solution of water differs from that dissolved in matter of heat, as it is supported by its adhesion to particles of air, and is not precipitated by cold. In this stratum it seems probable that the meteors called shooting stars are produced; and that they consist of electric sparks, or lightning passing from one region to another of those invisible fields of aeri-aqueous solution. These meteors appear to be lower than fire balls; but as they are in a much rarer medium than that in which lightning resides, and yet much denser than that in which fire balls are produced, they will be attracted at a much greater distance than the former, and at a less than the latter. From the rarity of the air, so small a sound will be produced by their explosion as not to reach the lower parts of the atmosphere.

The third region or stratum of air terminates, we may suppose, from where the twilight ceases to be refracted, i.e. where the air is 3000 times rarer than at the surface of the earth; and where it seems probable that the common air ends, and is surrounded by an atmosphere of inflammable gas, ten times rarer than atmospheric air. In this region, fire balls seem to pass, and the northern lights, to exist. A fire ball is mentioned by Dr. Blagden in the Philosophic transactions. It was seen in August 1783, and was estimated to be 60 or 70 miles high, and to move at the rate of 20 miles in a minute. The fire balls differ from lightning and from shooting stars in many particulars, as in their great bulk; their travelling horizontally for 1000 miles; their throwing off sparks in their passage; their colour; and their leaving a train of fire behind them, continuing about minute. They differ from the northern lights in not being diffused, but paſsing on in a defined line. and this in a region above the veſicular atmosphere, where the air is 3000 times rarer than at the surface of the earth. The following seems to be the most probable conjecture to account for these phenomena. There is probably a superincumbent stratum of inflammable gas, or over the common atmosphere, whose density must be ten times at least leſs dense than the air upon which it swims; like chemical ether floating upon water. Now a ball of electricity paſsing between the inflammable and common air, would set fire to them in a line as it paſsed along, and would occasion greater degrees of inflammation, or branches of fire in some parts of its course than in others; and would move with the greatest rapidity on account of the rarity of the medium. As they are a mile and more in diameter, they must be emitted from a large surface of electric matter. But what is there in nature that can attract them at so great a distance as a thousand miles, and also so forcibly as to cause their rapid motion??? The northern lights seem to be repelled or radiated from an accumulation of electricity in the north. Dr. Franklin very ingeniously accounts for them on principles of electricity. He premise the following electrical phenomena. 1st That all new fallen snow has much positive electricity upon its surface. (Cavallo says oftener negative than positive) 2nd That about 12° of latitude around the north pole are covered with a crust of eternal ice which is impervious to the electric fluid. 3rd That the dense part of the atmosphere rises but a few miles high; and that in the rare parts, the electric fluid will paſs to almost any distance. Hence he supposes that there must be a great accumulation of positive electricity on the fresh fallen snow in the polar regions, which not being able to paſs thro' the crust of ice into the earth, must rise into the rare air of the upper parts of the atmosphere which will least resist its paſsage; and paſsing towards the equator, must descend again into the dense atmosphere, and then into the earth in silent streams.

Before we conclude this lecture we shall make some observations on the use of Franklins by which we are enabled to arrest the flaming thunderbolt of heaven and snatch our persons and our houses from its fury. They should consist of a metalic rod at least half an inch thick and it is better to have them all of one piece than that they should consist of different pieces connected with each other, because when they consist of many pieces the electric fluid meets with considerable opposition in its paſsage through them and is partly conducted off at the union of these pieces. They should be fixed to the house by wooden clamps instead of iron and baked wood is preferable on account of its non conducting quality. It is not sufficient that they should continue to the surface of the ground but they ought to be extended several feet beneath it and in a direction from the building. They ought also to be extended five or six feet above the top of the building for a reason which is too obvious to mention. They should terminate in a sharp point which ought to be gilded or covered with black lead for iron attracts the oxygen of the atmosphere and thus the goodneſs of the conductor is diminished by its combination with an electric. Sharp points are preferable to blunt because they draw off the electricity in silent streams and repel the cloud beyond striking distance; whereas blunt points draw it off in larger quantities and attract the cloud within striking distance. This is evident from an experiment made with the electrical machine. Let a pair of scales be insulated and a piece of cotton suspended to one represent a cloud. Let this cloud be electrified and be made to paſs over sharp and blunt points the phenomena above stated will take place.

It is neceſsary to make a few remarks on personal security during a thunder storm. If you are in a house you should by all means keep at a distance from all metalic substances. In general it is best to avoid the chimney both because you will generally find metalic substances near it and also because it is the most elevated part of the house and lightning always prefers the nearest conductor when other circumstances are the same. If you are in the open field you should get within fifteen or twenty steps of a tree for if the lightning should come that way it will certainly strike at the tree as the highest object and you will be sufficiently remote from it to be perfectly secure from danger. If you wish a place of perfect security place yourself in a feather bed suspended to the ceiling by silken cords. But this is a method which will be resorted to only by the guilty wretch who trembles at the thought of death and not by virtue's ardent votary whose soul disdains the slavish fear of launching into the boundleſs ocean of eternity and supports him tranquil and unappalled amid the crush of worlds.

Lecture XVII.

Of Galvanism.

Electricity enriched by the labours of so many celebrated physicians seemed tending to a state of repose or to be occupied only in throwing more light upon truths already discerned, when the phenomena of those convulsive motions observed by a student of Galvani in the muscles of mice, frogs, and other animals which were made to communicate with metals, excited anew the attention and astonishment of philosophers. Electricity was immediately considered as the cause of those motions. A new branch of physics invited genius; it was seized with ardor: experiments were varied and multiplied: the phenomena which seemed at first confined to the animal kingdom were found to extend even to the dominion of chemistry on account of the decomposition of water which this new agency was seen to effect.

That this subject may be placed in a clear point of view before the student, it appears neceſsary to carry him back to its origin, and to shew him the steps of its advancement to its present state. The first traces of this species of electricity are found in the publication of in 1767. He mentions an experiment which is now well known. If we take two pieces of metal of different sorts, such as zinc and silver, and place them, the zinc upon the tongue, and silver under the tongue; in forming a communication between them, either by bringing the outer edges in contact, or by the interposition of some other piece of metal, he will experience a curious sensation, a kind of irritation, accompanied with a sort of cool subacid taste not exactly like, yet not much different from that which is produced by electricity. The effect is rather more remarkable when the zinc touches the tongue in a small part and the silver in a great proportion of its surface, than vice versa. Instead of applying the metals to the tongue, they may be placed in contact with the roof of the mouth as far back as poſsible, and on making the communication the taste or irritation is perceived. Different persons are variously affected by this application of metals. Not only this singular fact something like vitriol or sulphate of iron is observed; but oftentimes a flash of light is seen upon making experiments in a dark room, or with the eye shut. This phenomenon tho' belonging to the new branch of electricity, gave rise, at first, to no additional discovery. It was not till 1789 that another fact brought forth by chance gave an impulse to philosophy to enter upon a career which has been attended with the most interesting results. A student medicine at Bologna was engaged in dissecting a living mouse which he held in one hand; when having touched with a knife one of the nerves of the animal, he immediately felt a spasmodic convulsion similar to that which electricity occasions. Some time after a new discovery presented itself to Galvani. There had been placed upon a table where there was an electrical machine, frogs stripped of their skins: a student touched with the point of a knife the crural nerves of one of these animals, and instantly all the muscles of the frog experienced strong convulsions. He also observed that the same effect took place whenever sparks were drawn from the prime conductor. Galvani repeated the experiment and found that the convulsions took place only when the machine was in action, and that electricity was the real cause of them. He then discovered how the convulsions might be excited by forming a metalic communication between the muscles and the nerves of a frog without the aid of an electrical machine. To make the convulsions the stronger he found that different metals must be used. Let the muscles and nerves of a frog's leg be laid bare: on one place tinfoil, on the other a piece of silver; form a metalic communication between them and the convulsion will immediately succeed. Galvani endeavoured to explain these phenomena upon the supposition that the electricity of the animal was in an unbalanced state, and then by means of the metalic conductor, the equilibrium was suddenly restored, and convulsions were the consequence of that sudden restoration, as in the Leyden phial or charged bottle.

The celebrated Volta entertained an idea somewhat similar. He concluded that the nerves were the seat of negative electricity and the muscles of positive, and that the equilibrium was restored by metalic communication. This opinion was contested and overthrown by late experiments. To Volta, however, was reserved the establishment of this branch of science upon a real foundation. It had been particularly noted that the reunion of two different metals was an important circumstance in the succeſs of these experiments upon Frogs &c. It is in reality the contact of these two metals which determines the electric action: and this is the principal fact which leads to all the rest.

If two pieces of different metal, insulated, and having only their natural quantity of electricity be brought into contact, they are put into two opposite states, so that when we separate them one will exhibit signs of positive and the other signs of negative electricity. Take zinc and copper, each insulated, the zinc will be positively and the copper negatively electrified. This may be verified by the condenser after a number of contacts (see Cavallo on condenser). The electricity thus produced by the mere contact of two different metals is indeed very small: but the late discoveries of the ingenious Volta have shown the method of ascertaining that electricity in a remarkable degree, and thus has opened a new field for the most ardent philosophic enquiry.

Previous to the discoveries of Galvani, a variety of circumstances indicated a peculiar action arising from a combination of different metalic substances in certain cases. Thus it had been long observed that any liquid drank out of a pewter or tin veſsel had a very different taste from what it has when drank out of a glaſs veſsel. (This seems not to be in its proper place..... Where ought it to be then?)

Mercury retains its brilliancy when alone; but amalgamated with another metal it is tarnished or oxydated. Metals of tin and lead soon corrode. Metals soldered by the interposition of other metals soon tarnish where the different metals join. Copper, and sheating of ships fastened on with iron nails both corrode very soon at the place of contact. Zinc will remain in water any length of time alone, but if touched with silver both are soon oxydated. The action arising from the combination of three conductors, two metalic, the other a fluid, was particularly investigated by Volta who showed that the slight effect of a single combination might be extended to a prodigious degree by increasing the combination. As, for instance, if a single combination of zinc, silver, and water, produce a certain effect; a second combination united with it, they will together produce a greater effect.

But before we speak of these combinations and their astonishing effect, which are commonly called Galvanic batteries, (with more propriety Voltaic batteries) let us state the principal laws with respect to simple combinations. 1. Conductors of electricity are divided into two claſses the humid and the dry. To the latter belong metals, charcoal, and the like; to the former, water, soap, and any oxygenating fluids &c. (Cavallo) 2. The simplest combinations capable of producing Galvanic effects must consist of three conductors: two will not produce any sensible effect. If the three conductors be of the same claſs, the effect is seldom sensible. But if the combination consist of one conductor of one claſs, and two of the other, then the most powerful effects are produced. Thus if two different metals, and one humid substance be used, the combination is most powerful, and is said to be of the first order. If there be two of the second claſs and one of the first, it is said to be of the second order. When we drink out of a metalic cup, the combination is of the second order. 3. It appears indispensibly requisite in every Galvanic combination, that the conductors of one claſs should have some chemical action upon the conductor or conductors of the other claſs, without which circumstance the combinations of three bodies will have no Galvanic action. This action seems proportionate to the chemical action, and also appears to evince that such chemical action is the prime cause of the electrical phenomena. An union of zinc, copper or silver, and water, forms an active Galvanic combination. The water is found to oxydate the zinc in its usual state; but if one of the mineral acids be added the combination is much more active.— (See page 479–80 Cavallo 3. vol.) 4. When the three bodies which form a Galvanic combination of the first order are laid upon each other, but the lower and the upper do not touch, then the extremes are in opposite states of electricity. Thus let copper, zinc, and a moistened substance be laid upon each other; the copper or moist substance, whichever is the upper, will be positive, and the lower, viz. the zinc negative: and if the same combination be carried on to any extent, and the layers consist of an even number, one half will be in the positive state, and the other in the negative. 5. In this way the Galvanic effects may be increased to any degree, taking care that the intermediate combinations do not counteract each other; and