ed with stones, iron, or any heavy matter, will not overturn so easily, as when loaded with wood, hay, or any light article; for when the load is not higher than a b, fig. 22, a line from the centre of gravity will fall within the centre of the base at c; but if the load be as high as d, it will then fall outside the base of the wheels at e, consequently it will overturn. From this appears the error of those, who hastily rise in a coach or boat, when it is likely to overset, thereby throwing the centre of gravity more out of the base, and increasing their danger.

CHAPTER II.

ARTICLE 15.

OF THE MECHANICAL POWERS.

Having premised and considered all that is necessary for the better understanding those machines called mechanical powers, we now proceed to treat of them. They are six in number; namely:

The Lever, the Pulley, the Wheel and Axle, the Inclined Plane, and the Screw.

These are called Mechanical Powers, because they increase our power of raising or moving heavy bodies. Although they are six in number, yet they are all governed by one simple principle, which I shall call the First General Law of Mechanical Powers; it is this, *the momentums of the power and weight are always equal, when the engine is in equilibrio.*

Momentum, here means the product of the weight of the body multiplied into the distance it moves; that is, the power multiplied into its distance moved, or into its distance from the centre of motion, or into its velocity, is equal to the weight multiplied into its distance moved, or into its distance from the centre of motion, or into its velocity; or, the power multiplied into its perpendicular descent, is equal to the weight multiplied into its perpendicular ascent.

The Second General Law of Mechanical Powers, is,

The power of the engine, and velocity of the weight moved, are always in the inverse proportion to each other; that is, the greater the velocity of the weight moved, the less it must be; and the less the velocity, the greater the weight may be: and that universally in all cases.

The Third General Law, is,

Part of the original power is always lost in overcoming friction, inertia, &c., but no power can be gained by engines, when time is considered in the calculation.

In the theory of this science, we suppose all planes to be perfectly smooth and even, levers to have no weight, cords to be perfectly pliable, and machines to have no friction: in short, all imperfections are to be laid aside, until the theory is established, and then proper allowances are to be made for them.

ARTICLE 16.

OF THE LEVER.

A bar of iron, of wood, or of any other inflexible material, one part of which is supported by a fulcrum or prop, and all other parts turn or move on that prop, as their centre of motion, is called a lever; when the lever is extended on each side of the prop, these extensions are called its arms; the velocity or motion of every part of these arms, is directly as its distance from the centre of motion, by the third law of circular motion.

With respect to the lever, when in equilibrium,—Observe the following laws:—

1. The power and weight are to each other, inversely as their distances from the prop, or centre of motion.

That is, the power P, fig. 8, Plate I. which is one multiplied into its distance B C, from the centre 12, is equal to the weight 12 multiplied into its distance A B 1; each product being 12.

2. The power is to the weight, as the distance the weight moves, is to the distance the power moves, respectively.

That is, the power multiplied into its distance moved, is equal to the weight multiplied into its distance moved.

3. The power is to the weight, as the perpendicular ascent of the weight, is to the perpendicular descent of the power.

That is, the power multiplied into its perpendicular descent, is equal to the weight multiplied into its perpendicular ascent.

4. Their velocities are as their distances from their centre of motion, by the 3d law of circular motion, p. 28.

These simple laws hold universally true, in all mechanical powers or engines; therefore it is easy (from these simple principles) to compute the power of any engine, either simple or compound; for it is only to find how much swifter the power moves than the weight, or how much farther it moves in the same time; and so much is the power (and time of producing it) increased, by the help of the engine.

ARTICLE 17.

GENERAL RULES FOR COMPUTING THE POWER OF ANY ENGINE.

1. Divide either the distance of the power from its centre of motion, by the distance of the weight from its centre of motion. Or,

2. Divide the space passed through by the power, by the space passed through by the weight, (this space may be counted either on the arch, or on the perpendicular described by each,) and the quotient will show how much the power is increased by the help of the engine; then multiply the power applied to the engine, by that quotient, and the product will be the power of the engine, whether simple or compound.

EXAMPLES.

Let A B C, Plate I. fig. 8, represent a lever; then, to compute its power, divide the distance of the power P from its centre of motion B C 12, by the distance A B 1, of the weight W, and the quotient is 12: the power is increased 12 times by the engine; which, multiply by the power applied 1, produces 12, the power of the engine at A, or the weight W, that will balance P, and hold the engine in equilibrio. But suppose the arm A B to be continued to E, then, to find the power of the engine, divide the distance B C 12, by B E 6, and the quotient is two; which multiplied by 1, the power applied, produces 2, the power of the engine, or weight w to balance P.

Or divide the perpendicular descent C D of the power equal 6, by the perpendicular ascent E F equal 3; and the quotient 2, multiplied by the power P equal 1, produces 2, the power of the engine at E.

Or divide the velocity of the power P equal 6, by the velocity of the weight w equal 3; and the quotient 2, multiplied by the power 1, produces 2, the power of the engine at E. If the power P had been applied at 8, then it would have required to have been 1½ to balance W, or w: because 1½ times 8 is 12, which is the momentum of both weights W and w. If it had been applied at 6, it must have been 2; if at 4, it must have been 3; and so on for any other distance from the prop or centre of motion.

ARTICLE 18.

OF THE DIFFERENT KINDS OF LEVERS.

There are four kinds of Levers.

1. The most common kind, where the prop is placed between the weight and power, but generally nearest the weight, as otherwise, there would be no gain of power.

2. When the prop is at one end, the power at the other, and the weight between them.

3. When the prop is at one end, the weight at the other, and the power applied between them.

4. The bended lever, which differs only in form, but not in properties, from the others.

Those of the first and second kind, have the same properties and powers, and produce real mechanical advantage, because they increase the power; but the third kind produces a decrease of power, and is only used to increase velocity, as in clocks, watches, and mills, where the first mover is slow, and the velocity is increased by the gearing of the wheels.

The levers which nature employs in the machinery of the human frame, are of the third kind; for when we lift a weight by the hand, the muscle that exerts the force to raise the weight, is fastened at about one-tenth of the distance from the elbow to the hand, and must exert a force ten times as great as the weight raised; therefore, he that can lift 56 lbs. with his arm at a right angle at the elbow, exerts a force equal to 560 lbs. by the muscles of his arm.

ARTICLE 19.

OF COMPOUND LEVERS.

Several levers may be applied to act one upon another, as 2 1 3 in fig. 9, Plate I. where No. 1 is of the first kind, No. 2 of the second, and No. 3 of the third. The power of these levers, united to act on the weight W, is found by the following rule, which will hold universally true in any number of levers united, or wheels (which operate on the same principle) acting upon one another.

RULE.

1st. Multiply the power P, into the length of all the driving levers successively, and note the product.

2d. Then multiply all the leading levers into one another successively, and note the product.

3d. Divide the first product by the last, and the quotient will be the weight W, that will hold the machine in equilibrio.

This rule is founded on the first law of the lever, Art. 16, and on this principle; namely:

Let the weight W, and power P, be such, that when suspended on any compound machine, whether of levers united, or of wheels and axles, they hold the machine in equilibrio: then if the power P be multiplied into the radius of all the driving wheels, or lengths of the driving levers, and the product noted, and the weight W multiplied into the radius of all the leading wheels, or length of the leading levers, and the product noted, these products will be equal. If we had taken the velocities, or the circumferences of the wheels, instead of their radii, they would have been equal also.

On this principle is founded all rules for calculating the power and motion of wheels in mills, &c. See Art, 20.

EXAMPLES.

Given, the power P equal to 4, on lever 2, at 8 distance from the centre of motion. Required, with what force lever 1, fastened at 2 from the centre of motion of lever 2, must act, to hold the lever 2 in equilibrio.*

By the rule 4×8 the length of the long arm is 32, and this divided by 2, the length of the short arm, gives 16, the force required.

Then 16 on the long arm, lever 1, at 6 from the centre of motion. Required, the weight on the short arm, at 2, to balance it.

By the rule, 16×6=96, which divided by 2, the short arm, gives 48, for the weight required.

Then 48 is on the lever 3, at 2 from the centre. Required, the weight at 8 to balance it.

Then 48×2=96, which divided by 8, the length of the long arm, gives 12, the weight required.

Given, the power P=4, on one end of the combination

* In order to abbreviate the work, I shall hereafter use the following Algebraic signs; namely:

of levers. Required, the weight W, on the other end, to hold the whole in equilibrio.

Then by the rule, $4\times8\times6\times2=384$ the product of the power multiplied into the length of all the driving levers, and $2\times2\times8=32$ the product of all the leading levers, and $384\div32=12$ the weight W required.

ARTICLE 20.

CALCULATING THE POWER OF WHEEL WORK.

The same rule holds good in calculating the power of machines consisting of wheels, whether simple or compound, by counting the radii of the wheels as the levers; and because the diameters and circumferences of circles are proportional, we may take the circumferences instead of the radii, and it will be the same result. Then again, because the number of cogs in the wheels constitute the circle, we may take the number of cogs and rounds instead of the circle or radii, and the result will still be the same.

Let fig. 11, Plate II. represent a water-mill (for grinding grain) double geared.

Number 8 The water-wheel,
4 The great cog-wheel,
2 The wallower,
3 The counter cog-wheel,
1 The trundle,
2 The mill-stones,

And let the above numbers also represent the radius of each wheel in feet.

Now suppose there be a power of 500 lbs. on the water-wheel, required what will be the force exerted on the mill-stone, 2 feet from the centre.

The sign + plus, or more, for addition.
— minus, or less, for substraction.
× multiplied, for multiplication.
÷ divided, for division.
= equal, for equality.

Then, instead of 8 more 4 equal 12, I shall write $8+4=12$. Instead of 12 less 4 equal 8, $12-4=8$. Instead of 6 multiplied by 4 equal 24, $6\times4=24$. And instead of 24 divided by 3 equal 8, $24\div3=8$.

Then by the rule, $500 \times 8 \times 2 \times 1 = 8000$, and $4 \times 3 \times 2 = 24$, by which divide 8000, and it *quotes* 333,33 lbs. the power or force required, exerted on the mill-stone two feet from its centre, which is the mean circle of a 6 feet stone.—And as the velocities are as the distance from the centre of motion, by the third law of circular motion, Art. 13, therefore, to find the velocity of the mean circle of the stone 2, apply the following rule; namely:

1st. Multiply the velocity of the water wheel into the radii or circumferences of all the driving wheels, successively, and note the product.

2d. Multiply the radii or circumferences of all the leading wheels, successively, and note the product; divide the first by the last product, and the quotient will be the answer.

But observe here, that the driving wheels in this rule, are the leading levers in the last rule.

EXAMPLES.

Suppose the velocity of the water-wheel to be 12 feet per second; then by the rule $12 \times 4 \times 3 \times 2 = 288$ and $8 \times 2 \times 1 = 16$, by which divide the first product 288, and this gives 18 feet per second, the velocity of the stone 2 feet from its centre.

ARTICLE 21.

POWER DECREASES AS MOTION INCREASES.

It may be proper to observe here, that as the velocity of the stone is increased, the power to move it is decreased, and as its velocity is decreased, the power on it to move it is increased, by the second general law of mechanical powers. This holds universally true in all engines that can possibly be contrived; which is evident from the first law of the lever, when in equilibrium, namely, the power multiplied into its velocity or distance moved, is equal to the weight multiplied into its velocity or distance moved.

Hence the general rule to compute the power of any engine, simple or compound, Art. 17. If you have the moving power, and its velocity or distance moved, given, and the velocity or distance of the weight, then, to find the weight, (which, in mills, is the force to move the stone, &c.) divide that product by the velocity of the weight, or mill-stone, &c. and this gives the weight or force exerted on the stone to move it. But a certain qauntity or proportion of this force is lost from friction in order to obtain a velocity to the stone; which is shown in Art. 31.

ARTICLE 22.

NO POWER GAINED BY ENLARGING UNDERSHOT WATER-WHEELS.

This seems a proper time to show the absurdity of the idea of increasing the power of the mill, by enlarging the diameter of the water-wheel, on the principle of lengthening the lever; or by double gearing mills where single gears will do; because the power can neither be increased nor diminished by the help of engines, while the velocity of the body moved is to remain the same.

EXAMPLE.

Suppose we enlarge the diameter of the water-wheel from 8 to 16 feet radius, fig. 11, Plate II. and leave the other wheels unaltered; then, to find the velocity of the stone, allowing the velocity of the periphery of the water-wheel to be the same (12 feet per second;) by the rule $12\times4\times3\times2=288$, and $16\times2\times1=32$, by which divide 288, which gives 9 feet in a second, for the velocity of the stone.

Then, to find the power by the rule for that purpose, Art. 20, $500\times16\times2\times1=16000$, and $4\times3\times2=24$, by which divide 16000, it gives 666,66 lbs. the power. But as velocity as well as power, is necessary in mills, we shall be obliged, in order to restore the velocity, to enlarge the great cog-wheel from 4 to 8 radius.

Then, to find the velocity, $12\times8\times3\times2=576$, and $16\times2\times1=32$, by which divide 576, it gives 18, the velocity as before.

Then, to find the power by the rule, Art. 20, it will be 333,33 as before.

Therefore no power can be gained, upon the principle of lengthening the lever, by enlarging the water-wheel.

The true advantages that large wheels have over small ones, arise from the width of the buckets bearing but a small proportion to the radius of the wheel; because if the radius of the wheel be 8 feet, and the width of the bucket or float-board but 1 foot, the float takes up 1-8 of the arm, and the water may be said to act fairly upon the end of the arm, and to advantage. But if the radius of the wheel be but 2 feet, and the width of the float 1 foot, part of the water will act on the middle of the arm, and of course, to disadvantage, as the float takes up half the arm. The large wheel also serves the purpose of a fly-wheel (Art. 30;) it likewise keeps a more regular motion, and casts off back water better. (See Art. 70.)

But the expense of these large wheels is to be taken into consideration, and then the builder will find that there is a maximum size, (see Art. 44,) or a size that will yield him the greatest profit.

ARTICLE 23.

NO POWER GAINED, BUT SOME LOST, BY DOUBLE GEARING MILLS.

I might go on to show that no power or advantage is to be gained by double gearing mills, upon any other principles than the following; namely:

1. When the motion necessary for the stone cannot be obtained without having the trundle too small, we are obliged to have the pitch of the cogs and rounds, and the size of the spindle, large enough to bear the stress of the