Hence it was that ARCHIMEDES was able to say, that he could lift the world if he had a place on whic[illegible] lever.

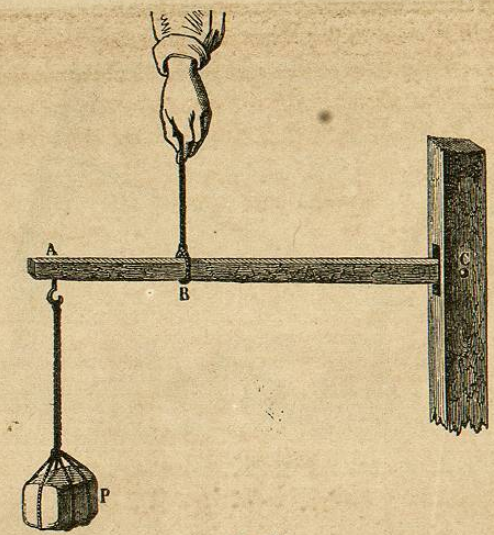

Fig. 17.

Since the effect of a force increases with its arm of lever it is necessary, in order that the power and resistance may be in equilibrium, that they should be to each other inversely as their lever arms. That is, if the power is three times the resistance, the lever arm of the former should only be one third as long as that of the latter, and so on. If the power is equal to the resistance, they will be in equilibrium when their lever arms are equal.

From what has been said, it follows, that the power is always greater than the resistance in the third class of levers, and less than it, in the second class. In the first class the power may be either greater or less than the resistance. We say in common language

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Between the power and velocity?

that there is a gain of power in using a lever of the third class, and a loss of power in using one of the second class.

In performing any work with a lever, the paths passed over by the points of application of the power and resistance are proportional to their lever arms; that is, the longer the lever arm the greater the path passed over, and the greater its velocity. This is expressed by saying, that *what is gained in power is lost in velocity.* It is for this reason that we say there is no real gain of power in the employment of a lever.

Examples of Levers.

32. Levers are of continual use in the arts, forming component parts of nearly every machine.

Fig. 18.

A pair of scissors affords an example of the first class of levers. The fulcrum is at *C*, Fig. 18, the hand furnishes the power, and the substance to be cut the resistance.

The common balance, yet to be described, is a lever of this class as is also the handle of a pump.

The ordinary nut-cracker is an example of levers of the

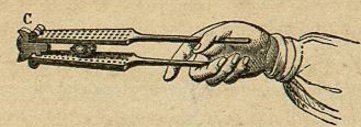

Fig. 19.

second class. The fulcrum is at *C*, Fig. 19; the power is the hand, and the resistance is the nut to be cracked.

Is there any gain of power in using a lever? (**32**) Applications. Explain the scissors. The nut-cracker.

The oars of a boat are levers of the second class. The end of the oar in the water is the fulcrum, the hand is the power, and the boat, or rather the resistance of the water which it has to overcome, is the resistance. The shears employed for cutting metals belong to this class of levers.

The treadle of a flax-spinner, or of a lathe, is an example of a lever of the third kind. The fulcrum is at *C*, Fig. 20, the foot is the power, and the work to be done is the resistance.

Fig. 20.

The bones of the animal frame are many of them levers of this class. Thus, in the bone of the forearm in man, the elbow joint is the fulcrum, the muscle attached just below the joint is the power, and a weight to be raised is the resistance.

Other Machines.

33. Besides the lever there are two other simple machines, the *cord* and the *inclined plane*. The former re-

Oars of a boat. Treadle of a spinner. *Bone of the forearm.* (**33.**) What are the other simple machines?

quires no description, and the latter will be explained further on. From these machines, as elements, are formed by combination, *the pulley*, *the wheel and axle*, *the screw*, and *the wedge*. These seven make up what are commonly called the *Mechanical Powers*, and from them may be constructed every machine, however complicated. A full explanation of these does not fall within the design of this work. The reader is therefore referred for an account of them to the *Mechanics*. (Peck's Mechanics, Chapter IV.)

III.—PRINCIPLES DEPENDENT ON THE ATTRACTION OF GRAVITATION.

Universal Gravitation.

34. THE earth exerts a force of attraction upon all bodies near it, tending to draw them towards its centre. This force, called the *Force of Gravity*, when unresisted imparts motion, and the body is said *to fall;* when resisted it gives rise to pressure, which is called *Weight*.

NEWTON showed that the force of gravity, as exhibited at the earth's surface, was only a particular case of a general attraction extending throughout the Universe, and continually tending to draw bodies together. This general attraction he called *Universal Gravitation*. It is mutually exerted between any two bodies whatever, and it is by virtue of it that the heavenly bodies are retained in their orbits.

The law of universal gravitation may be easily explained. If we take the mutual attraction of two units of mass, at a unit's distance from each other, as 1, then will their mutual attraction at any other distance be equal to 1 divided by the square of that distance; thus, if the distance is 2, their attraction will be $\frac{1}{4}$ of what it was at the

What machines are formed by combinations of simple machines? Name the seven mechanical powers. (**34.**) What is the Force of Gravity? What is its effect when unresisted? When resisted? What is Universal Gravitation? *Explain the law of Universal Gravitation.*

distance 1; if their distance is 3, their attraction will be $\frac{1}{9}$ of what it was at the distance 1, and so on. If one of the masses contains *m* units of mass, and the other one unit, the force will be *m* times as great as though they were both units of mass; that is, the attraction will be equal to *m*, divided by the square of the distance between the bodies. If the second body contain *n* units of mass, the attraction will be *n* times as great as before; that is, it will be *mn*, divided by the square of the distance between the bodies.

This law, discovered by NEWTON, may be expressed as follows: *Any two bodies exert upon each other a mutual attraction, which varies directly as the product of their masses, and inversely as the square of their distance apart.*

Effect of Gravitation on the Planets.

35. It is by the influence of gravitation that the planets are retained in their orbits. Their motion is the same as though they had been projected into space with an impulse, and then continually drawn from the right lines along which inertia tends to carry them, by the attraction of the sun. The planets also attract the sun, but their masses being exceedingly small in comparison with that of the sun, their effects in disturbing its position are exceedingly small. The orbits of the planets are ellipses differing but little from circles.

Force of Gravity.

36. The FORCE OF GRAVITY is that force of attraction which the earth exerts upon all bodies, tending to draw them towards its centre.

As has been stated, it is only a particular case of Universal Gravitation. It is, therefore, subject to the same law, that is, it varies directly as the mass of the body acted

Enunciate NEWTON's law. (**35.**) What is the effect of gravitation on the planets? What are the orbits of planets? (**36.**) What is the Force of Gravity? How does it vary?

upon, and inversely as the square of its distance from the centre of the earth.

The shape of the earth has been shown by careful measurement to be that of a spheroid; that is, of a sphere slightly flattened at the poles. The mean radius is a little less than 4000 miles. On account of the flattening of the earth at the poles, different points are at slightly different distances from the centre, and consequently the force of gravity varies slightly at different places on the surface. For ordinary purposes, however, we may regard the earth as a perfect sphere, and the force of gravity as constant all over its surface.

Vertical and Horizontal Lines.

37. A VERTICAL LINE is a line along which a body falls freely. All vertical lines are directed towards the centre of the earth, but for places near together they may be regarded as parallel.

In Fig. 21, the lines *ao* and *bo* are verticals, but if they are not far apart, their convergence is so small that they may be taken as

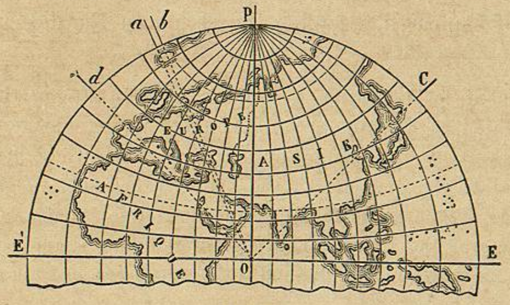

Fig. 21.

parallel. If, however, their distance apart is considerable, they can not be regarded as parallel. A man standing erect has his body in

What is the shape of the earth? (**37.**) What is a Vertical Line? Where do verticals meet? When may they be considered parallel? *When not parallel? Illustrate.*

a vertical, and it may happen that two persons on opposite sides of the globe, as at E and E', may both stand erect, and yet their heads be turned in exactly opposite directions, their feet being turned towards each other. Points where this may happen are said to be *antipodes*.

A HORIZONTAL LINE, or PLANE, at any place is one which is perpendicular to a vertical line at that place. The surface of still water is horizontal, or *level*. For small areas this surface may be regarded as a plane, but when a large surface is considered, as the ocean, it must be considered as curved, conforming to the general outline of the earth's surface.

Upon the principle of verticals and horizontals, all of our instruments for levelling and making astronomical observations are constructed.

The Plumb-Line.

38. A PLUMB-LINE, is a line having a heavy body, usually of lead, suspended at one of its ends. When the other end is held in the hand, the lead, tending towards the centre of the earth, stretches the string in the direction of the force of gravity.

It is used for indicating a vertical line. In Engineering and Architecture it is of continual use. For determining whether a wall is vertical, it is accompanied by a square plate, whose length is just equal to the diameter of the cylindrical leaden weight, and which has a hole at its middle point, just large enough to admit the passage of the string. The edge of the plate is applied to the masonry, as shown in Fig. 22, and if the *plumb-bob* just touches the wall, it must be vertical.

Weight.

39. The WEIGHT of a body is the pressure which it

What are antipodes? What is a Horizontal Line, or Plane? Level? Applications to instruments. (**38.**) What is a Plumb-Line? Describe it and its use. (**39.**) What is Weight?

exerts upon any body that prevents it from falling towards the earth.

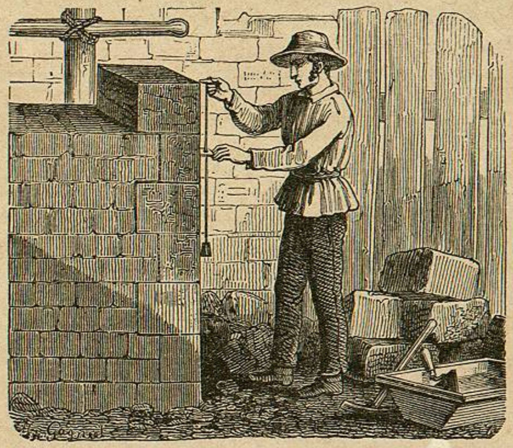

Fig. 22.

The weight of a body is due to the force of gravity, acting upon all of its particles, but it must not be confounded with the force of gravity. Weight is only the effect of gravity when resisted; when gravity is unresisted it produces quite another effect, that is, motion.

At the same place the weights of bodies are proportional to their masses, or the quantities of matter which they contain. We shall see hereafter that the weight of bodies may be determined by means of the balance; the force of gravity is determined by the velocity which it can impart to a body in a certain time, as will be shown more fully hereafter.

Centre of Gravity.

40. The CENTRE OF GRAVITY of a body is that point through which the direction of its weight always passes.

We have seen that the weight of a body is the resultant of the action of gravity upon all of its particles. It is shown

Is weight the same as gravity? How is weight determined? How is gravity measured? (**40.**) What is the Centre of Gravity?

in Mechanics, that whatever may be the form of a body, or whatever may be its position, the direction of its weight always passes through a single point. This point is the *centre of gravity.*

The determination of the centre of gravity in the general case requires the aid of mathematics, but in many cases its position is evident. In an uniform straight bar, it is at its middle point. In a square, or a rectangular, or a circular, or an elliptical disk it is at its centre, or middle point, and so on.

Equilibrium of heavy Bodies.

41. The centre of gravity being the point at which the weight is applied, it follows that, if this point is held fast by any support whatever, the effect of the weight is completely counteracted, and the body will be in a state of equilibrium.

If a body has but a single point of support, it can only be in equilibrium when its centre of gravity lies somewhere on a vertical through that point. An example is shown in Fig. 23, which represents a boy balancing a cane upon his finger. In the figure, g is the centre of gravity, and that point must be kept exactly over the point of support. This is a case of *unstable equilibrium.*

Fig. 23.

If a body has but two points of support, it can

Where is the centre of gravity of a straight line? Of a square? Rectangle? Circle? Ellipse? (**41.**) When is a body in equilibrium? When a body rests on a point, where must the centre of gravity be? Example.

only be in equilibrium when its centre of gravity lies in a vertical drawn through some point of the line joining these two points. An example is shown in Fig. 24, which represents a man standing on stilts. To be in equilibrium, his centre of gravity must be exactly over the line joining the feet of his stilts. This is also a case of *unstable equilibrium.*

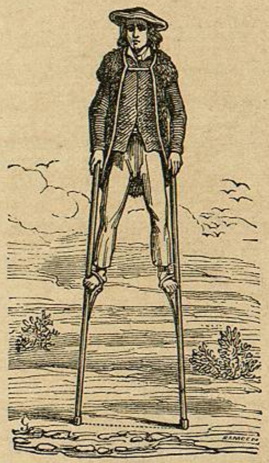

Fig. 24.

Fig. 25.

The art of balancing, in which circus-riders and rope-dancers are so expert, consists in skillfully keeping the centre of gravity supported.

If a body has three supports not in a straight line, it will be in equilibrium when the centre of gravity lies on a vertical drawn through any point of the triangle formed by joining these points. An example is shown in Fig. 25, which represents a three-legged table. The centre of gravity being at g, the table will be in equilibrium so long as the vertical through that point pierces the triangle formed by uniting the feet of the table.

When it rests on two points? Example. When on three points? Example.

If a body has four or more supports, the condition of equilibrium will be analogous to that just explained. In this case, if the outer points of support be joined by lines, they will form a polygon, called the *Polygon of Support*, and the body will be in equilibrium when its centre of gravity is on a vertical drawn through any point of this polygon.

Different kinds of Equilibrium.

42. When bodies are only acted upon by the force of gravity, and have one or more points of support, three kinds of equilibrium may exist: *Stable, Unstable, and Neutral Equilibrium.*

1. *Stable Equilibrium.*—A body is in *stable equilibrium*, when, on being slightly disturbed from its state of rest, it tends of itself to return to that state.

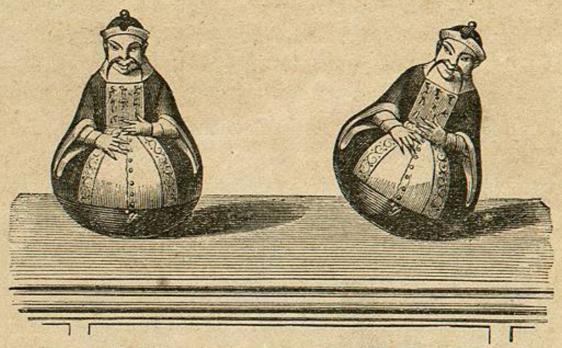

Fig. 26. Fig. 27.

This will be the case when the centre of gravity is lower in its position of rest than it is in any of the neighboring positions, for in this case the weight of the body acting at

When on four or more points? What is the Polygon of Support? (**42.**) What are the three cases of equilibrium? What is Stable Equilibrium? Illustrate.

the centre of gravity tends to keep it in the lowest position. If slightly disturbed from the lowest position, the weight will act to draw it back, and so establish the equilibrium.

We have an example of stable equilibrium represented in Figs. 26 and 27, which represent images often met with in the toy shops. If the image be inclined to one side, as shown in Fig. 27, it will by its own weight right itself, and take the position shown in Fig. 26. These figures are hollow and light, and are ballasted with lead at their lower part so as to throw the centre of gravity very low. The result is, that when the figure is inclined, the centre of gravity is raised, and the weight acts to restore it. The figure only settles in its primitive state of rest after several oscillations, which are due to the inertia of the body. The explanation of this oscillation is the same as that given for the oscillation of the pendulum.

2. *Unstable Equilibrium.*—A body is in *unstable equilibrium*, when, on being slightly disturbed from its state of rest, it does not tend to return to that state, but continues to depart from it more and more.

This will be the case when the centre of gravity is higher in its position of rest than in any of the neighboring positions. When the body is slightly disturbed, the weight acts not only to prevent its return, but also to cause it to descend still lower.

We have an example of unstable equilibrium shown in Figs. 22 and 23. In Fig. 22, the cane may overturn in any direction, whilst in Fig. 23, the man will overturn about the line joining the bottom of his stilts.

3. *Neutral Equilibrium.*—A body is in *neutral equilibrium*, when, on being slightly disturbed, it has no tendency either to return to its primitive state, or to depart further from it.

This will be the case when the centre of gravity is at the

Example. What is Unstable Equilibrium? Illustrate. *Examples.* What is Neutral Equilibrium? Illustrate.