same height in its position of rest as in the neighboring positions.

We have an example of this kind of equilibrium in a ball resting on a horizontal table.

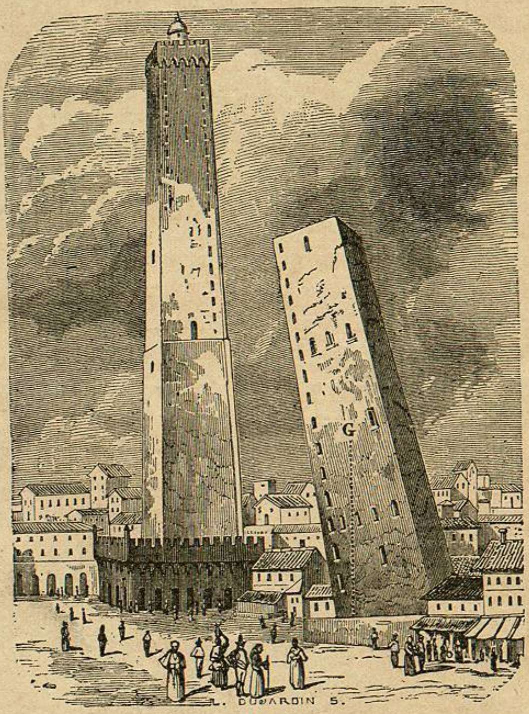

Fig. 28.

Stability of Bodies.

43. From what has been said in the preceding articles, it follows that bodies will in general be most stable when their bases are largest. For in such cases, even after a considerable inclination, the line of direction of the weight will

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Example. (**43.**) What bodies are most stable?

pass within the original polygon of support, and the weight will act to return the body to its original state of rest. Hence it is that we find chairs, lamps, chandeliers, and many other familiar utensils constructed with broad bases, to render them more stable.

The leaning tower of Pisa is so much inclined that it appears about to fall; yet it stands, because the vertical through the centre of gravity passes within the base of the tower. Fig. 28 represents a tower at Bologna, which is even more inclined than that at Pisa. This tower was built in the year 1112, and received its inclination from unequal settling of the ground on which it was built. It does not fall, because the vertical through the centre of gravity, *G*, passes within its base.

In the cases considered, the position of the centre of gravity remains the same for the same body. With men and animals the position of the centre of gravity changes with every change of attitude, which requires a proper adjustment of the feet, to maintain a position of stability.

Fig. 29.

Fig. 30.

When a man carries a burden, as shown in Fig. 29, he leans forward, that the direction of his own weight with that of his burden

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Explain the stability of the towers of Pisa and Bologna. How do men and animals maintain a stable position? Illustrate.

may pass between his feet. When a man carries a weight in one hand, as shown in Fig. 30, he throws his body toward the opposite side for the same reason.

In the art of rope-dancing, the great difficulty consists in keeping the centre of gravity exactly over the rope. To attain this result the more easily, a rope-dancer carries a long pole, called a balancing pole, and when he feels himself inclining towards one side, he advances his pole towards the other side, so as to bring the common centre of gravity over the rope, thus preserving his equilibrium. The rope-dancer is in a continual state of unstable equilibrium.

The Balance.

44. A Balance is a machine for weighing bodies.

Balances are of continual use in commerce and the arts, in the laboratory, and in physical researches; they are consequently extremely various in their forms and modes of construction. We shall only describe that form which is in most common use in the shops.

It consists of a metallic bar, *AB* (Fig. 31), called the *Beam*, which is simply a lever of the first order. At its middle point is a knife-edged axis, *n*, called the *Fulcrum*. The fulcrum projects from the sides of the beam, and rests on two supports at the top of a firm and inflexible standard. The knife-edged axis, and the supports on which it rests, are both of hardened steel, and nicely polished, in order to make the friction as small as possible. At the extremities of the beam are suspended two plates or basins, called *Scale Pans*, in one of which is placed the body to be weighed, and in the other the weights of iron or brass to counterpoise it. Finally, a needle projecting from the beam, and playing in front of a graduated scale, *a*, serves to show when the beam is exactly horizontal.

Explain the principle of rope-dancing. (**44.**) What is a balance? Explain the details of the common Balance. The Beam. The Fulcrum. The Scale Pans. The Scale.

To weigh a body, we place it in one of the scale pans, and then put weights into the other pan until the beam becomes horizontal. The weights put in the second pan indicate the weight of the body.

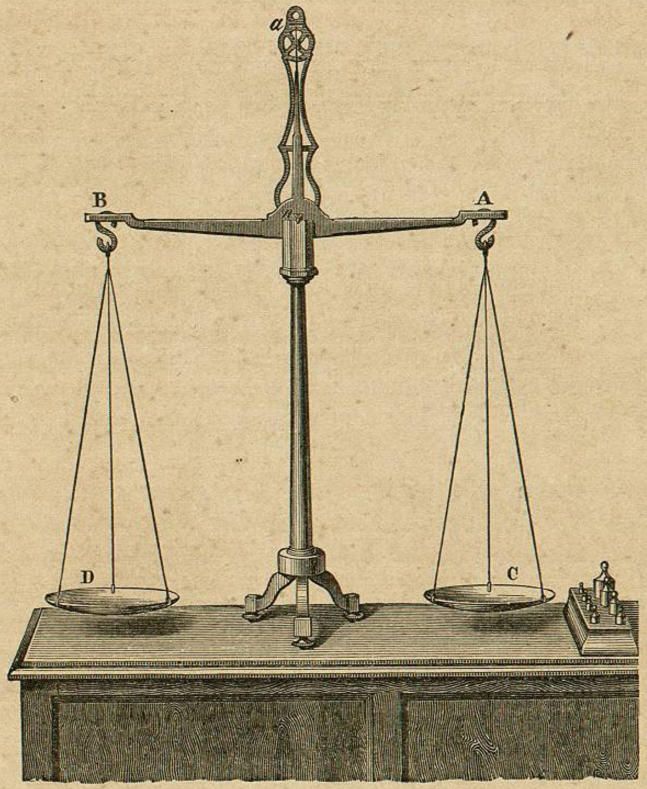

Fig. 31.

How are bodies weighed?

Requisites for a good Balance.

45. A good balance ought to satisfy the following conditions:

1. The lever arms, *An* and *Bn*, should be exactly equal.

We have seen in discussing the lever, that its arms must be equal, order that there may be an equilibrium between the power and resistance, when these are equal. If the arms are not equal, the weights placed in one scale pan will not indicate the exact weight of the body placed in the other.

2. The balance should be *sensitive;* that is, it should turn on a very small difference of weights in the two scale pans.

This requires the fulcrum and its supports to be very hard and smooth, so as to produce little friction. By making the needle long, a slight variation from the horizontal will be more readily perceived.

3. The centre of gravity of the beam and scale pans should be slightly below the edge of the fulcrum.

If it were in the edge of the fulcrum, the beam would not come to a horizontal position when the scales were equally loaded, but would remain in any position where it might chance to be placed. If it were above the edge of the fulcrum, the beam would remain horizontal if placed so, but if slightly deflected, it would tend to overturn by the action of the weight of the beam.

The nearer the centre of gravity comes to the edge of the fulcrum, the more accurate it will be; but at the same time, it would turn more slowly, and might finally come to turn too slowly to be of use for weighing.

It is to be observed that when the scale pans are heavily loaded, an increased weight is thrown on the fulcrum, which

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(**45.**) Explain the requisites of a good balance. 1. Lever arms. *Illustrate.* 2. Sensitiveness. *Illustrate.* 3. Position of centre of gravity. *Illustrate.*

causes an increase of friction, and consequently a diminution of sensitiveness.

Methods of Testing a Balance.

46. To see whether the arms are of equal length, let a body be placed in one scale pan, and counterbalanced by weights put in the other; then change places with the body and the weights. If the beam remains horizontal after this change, the arms are of equal length, otherwise the balance is *false.*

To test the sensitiveness, load the balance and bring the beam to a horizontal position, then deflect it slightly by a small force and see whether it returns slowly to its former position. It ought to come to a state of rest by a succession of oscillations.

Method of weighing correctly with a false Balance.

47. To weigh a body with a false balance, place it in one scale pan and counterbalance it by any heavy matter, as shot or sand, placed in the other pan. Then take out the body and replace it by weights which will exactly restore the equilibrium of the balance. The weights will be exactly equal to the weight of the body. The reason for this method is apparent.

Laws of falling bodies.

48. When bodies starting from a state of rest fall freely in vacuum, that is, without experiencing any resistance, they conform to the following laws:

1. *All bodies fall equally fast.*

(**46.**) How is a balance to be tested? (**47.**) How may a body be weighed correctly by a false balance? (**48.**) What is the first law of falling bodies?

When resisted by the air, bodies whose bulk is very large in proportion to their weight, fall more slowly than those whose bulk is small; thus, a soap-bubble falls more slowly than a bullet.

2. *The velocities acquired during the fall are proportional to the times occupied in falling.*

A body acquires a velocity of $32\frac{1}{6}$ feet in one second; it will therefore acquire a velocity of $64\frac{1}{3}$ feet in two seconds, a velocity of $96\frac{1}{2}$ feet in three seconds, and so on.

3. *The spaces passed over are proportional to the squares of the times occupied in falling.*

A body falls from rest through $16\frac{1}{12}$ feet in one second; it will therefore fall $4 \times 16\frac{1}{12}$, or $64\frac{1}{3}$, in two seconds, $9 \times 16\frac{1}{12}$, or $144\frac{3}{4}$ feet, in three seconds, $16 \times 16\frac{1}{12}$, or $257\frac{1}{3}$ feet in four seconds, and so on.

Fig. 32.

The first law is verified by the following experiment. A glass tube, six feet long (Fig. 32), is closed at one end, and at the other it has a stop-cock, by which it can be closed or opened at pleasure. A small leaden ball and a feather are introduced within the tube. So long as the tube is full of air, if it be suddenly inverted, it will be observed that the ball reaches the bottom sooner than the feather. If now the air be exhausted by means of an air-

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Effect of atmospheric resistance. What is the second law? *Illustrate.* Third law? *Illustrate.* How is the first law verified?

pump, and the tube suddenly inverted, both the ball and the feather will be seen to fall through the length of the tube in the same time. This experiment, besides verifying the law, shows also that the air offers a resistance, which is greater for light than for heavy bodies. This resistance is proportional to the surface offered to the direction of the fall.

The second law is a consequence of inertia and the continued action of gravity. The velocity generated in the first second is to be added to that generated in the next second, to obtain the velocity generated in two seconds. This must be twice that generated in the first second. This again must be added to that generated in the third second, to obtain that generated in three seconds. This then must be three times that generated in the first second, and so on.

The explanation of the third law will be better understood after having considered the nature of the inclined plane, which is discussed in the succeeding articles.

The Inclined Plane.

49. An Inclined Plane is a plane which is inclined to a horizontal plane; thus, *AB*, Fig. 33, is an inclined plane.

When a body rests on a horizontal plane, as for example on a table, the action of gravity tending to draw it down is completely counteracted by the resistance of the plane, and it remains at rest. It is not so, however, when a body is placed upon an inclined plane. In this case, the action of gravity may be resolved into two components, one perpendicular to the plane, and the other parallel to it. The action of the first component is counteracted by the resistance of the plane, whilst the second component causes

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What other principle does the experiment show? Explain the reason of the second law. (**49.**) What is an Inclined Plane? Explain its principle.

the body to move down the plane. Now, this last force is only a fraction of the weight of the body, as a fourth, a fifth, or a sixth, according to the inclination, but it obeys the same laws that the entire force would, in causing a body to fall.

Verification of the third Law of falling Bodies.

50. To verify the third law of falling bodies, we construct a plane with a slight inclination and divide it into 100 equal parts, as shown in Fig. 33. We then ascertain by successive trials at what division of the scale a leaden ball must be placed to roll to the bottom *A*, in one second; suppose at the sixth division. If now the ball be placed at the twenty-fourth division, it will roll to the bottom in two seconds; if placed at the fifty-fourth division, it will roll down in three seconds; if placed at the ninety-sixth division, it will roll down in four seconds, and so on.

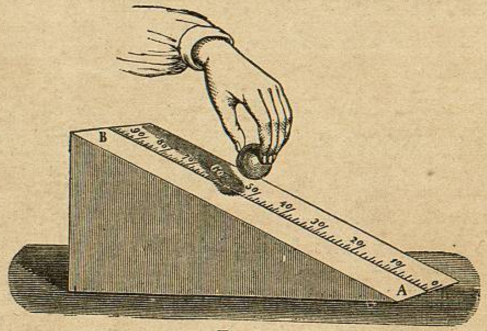

Fig. 33.

Hence, we conclude that, *the spaces passed over are proportional to the squares of the times.*

(**50.**) How is the third law of falling bodies verified?

Applications of the Inclined Plane.

51. When a body is placed upon an inclined plane, that component of its weight which acts to move it down the plane, becomes smaller as its inclination diminishes. Hence, the force required to draw a body up an inclined plane, will become smaller as the inclination diminishes. This principle is often utilized in the Arts; thus, to raise a heavy body to a height, we construct an inclined plane, up which it may be easily drawn.

It is in accordance with this principle that roads are constructed to ascend high hills and mountains, as shown in Fig. 34. Such a road consists of a succession of planes lying in different directions, which may be equally or unequally inclined to the horizon.

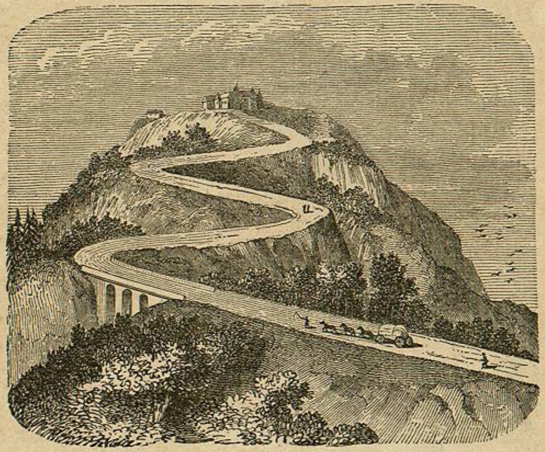

Fig. 34.

(**51.**) What is the use of the inclined plane in the Arts? Explain its application to roads.

It is according to the principle of the inclined plane that water flows along rivers and canals. The steeper the inclined planes which form their beds, the more rapid their currents.

In mechanics, two inclined planes, wound about a cylinder, constitute the screw; hence the principle of the screw is but a modification of that of the inclined plane. The wedge is made up of two inclined planes, placed back to back; hence its principle is also but a modification of that of the inclined plane.

The Pendulum.

52. A Pendulum is a heavy body suspended from a horizontal axis about which it is free to vibrate. Thus, the ball *m*, suspended from *C*, by a string, Figs. 35 and 36, is a pendulum.

Fig. 35.

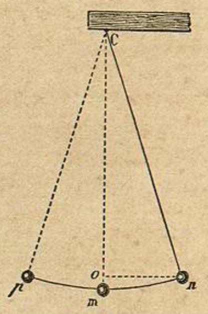

Fig. 36

When the centre of the ball, *m*, is exactly below the point of suspension *C*, Fig. 35, it is in equilibrium, for in that position the action of gravity is resisted by the tension of the string. If, however, the ball be drawn aside to *n*, Fig. 36, it is no longer in equilibrium, for in that position the force of gravity acts to draw it back to *m*, at which point it will arrive with the same velocity as though it had fallen through the vertical height *om*. In consequence of its inertia and acquired velocity, the ball does not stop at *m*, but moves on towards *p*. In descending from *n* to *m*, the force of gravity acts as an accelerating force, but in ascending from *m* to *p*, it acts as a retarding force, hence the ball moves slower and slower till it reaches *p*. The distance *mp* would be rigorously equal to *mn*, were it not for the resistance of the air.

The ball, having reached *p*, is in the same state as it was at *n*; the weight again acts to draw it back to *m*, whence, by virtue of its inertia and velocity, it again rises to *n*, and so on indefinitely.

This backward and forward motion is called *Oscillatory Motion.* A single excursion from *n* to *p*, or from *p* to *n*, is called a *Simple Oscillation*, or *Vibration.* An excursion from *n* to *p*, and back again to *n*, is called a *Double Oscillation.* The angle, *pCn*, is called the angle of the *Amplitude* of the oscillation.

In consequence of the resistance of the air, the amplitude is continually diminishing, and the ball eventually comes to rest, though often not till after the lapse of some hours.

Simple and Compound Pendulums.

53. A Simple Pendulum is such a pendulum as would be formed by suspending a single material point, with a string destitute of weight.

Such a pendulum may exist in theory, and is thus useful in arriving at the laws of oscillation, but in practice it can only be approximated to by making the ball very small and the string very fine.

A Compound Pendulum is any heavy body which is free to oscillate about a horizontal axis.

It may be of any form, but in general it consists of a stem *T*, Fig. 38, which is either of wood or metal. The stem terminates above in a thin and flexible plate, *a*, usually of steel; it terminates below in a disk of metal *L*, called the *bob*, which disk is of a lenticular shape, that the resistance of the air to its motion may be as little as possible.

Explain the flow of rivers. What is the screw? What is the wedge? On what principle do they act? (**52.**) What is a Pendulum? *What causes the pendulum to vibrate? Explain the action in detail.*

What is Oscillary Motion? What is an Oscillation or Vibration? What is its Amplitude? What effect has the air on vibration? (**53.**) What is a Simple Pendulum? *Is it real or ideal?* What is a Compound Pendulum? *Explain its construction.*