Laws of Oscillation of the Pendulum.

54. The oscillations of the pendulum take place in accordance with the following laws:

1. *For pendulums of unequal lengths, the times of oscillation are proportional to the square roots of their lengths.*

2. *For the same pendulum, the time of oscillation is independent of the amplitude, provided the amplitude be small.*

3. *For pendulums of the same length, the time of oscillation is independent of the nature of the material.*

Pendulums of wood, iron, copper, glass, all being of the same length, will all oscillate in the same time.

4. *For the same pendulum at different places, the times of oscillation are inversely as the square roots of the force of gravity at those places.*

These laws are deduced from a course of mathematical reasoning on the theoretical simple pendulum, but they may be verified experimentally by employing a very small ball of platinum, or other heavy metal, and suspending it with a very fine silk thread.

To verify the first law with such a pendulum, we begin by making it vibrate, and then counting the number of vibrations in one minute. Suppose, for example, that it makes seventy-two per minute. Now make the string four times as long as before, and it will be found that the pendulum makes only thirty-six oscillations per minute. If the string is made nine times as long as in the first instance, it will be found that the pendulum makes only twenty-four oscillations per minute, and so on. In the second case the time of oscillation is twice as great, and in the third case it is three times as great as in the first case. Now, because two, three, &c., are the square roots of four, nine, &c., it follows that the law is verified.

To verify the second law, let the same pendulum oscillate, at first

(**54.**) What is the first law of vibration? The second law? The third law? *Illustrate.* The fourth law? *How are these laws deduced? How is the first law verified? How is the second law verified?*

through an arc, *pn*, and then through any other arc, *rg*; it will be found that the number of oscillations per minute is the same in each case. Hence the law is verified. It is to be observed that the law does not hold true unless the arcs, *pn* and *rg*, are very small, that is, not more than three or four degrees.

The property of pendulums, that their times of oscillation are independent of the amplitude of vibration, is designated by the name *isochronism*, from two Greek words signifying *equal times*; oscillations performed in equal times are called *isochronal*.

Galileo first discovered the fact that small oscillations of a pendulum were isochronal, towards the end of the sixteenth century. It is stated that he was led to the discovery by noticing the oscillations of a chandelier suspended from the ceiling of the Cathedral of Pisa.

Applications of the Pendulum.

55. On account of the isochronism of its vibrations, the pendulum has been applied to regulate the motion of clocks. It was first used for this purpose in 1657, by Huyghens, a Dutch philosopher. The motive power of a clock is sometimes a weight acting by a cord wound around a drum, and sometimes a coiled spring similar to a watch spring. These motors act to set a train of wheel-work in motion, which in turn imparts motion to the hands that move round the dial to point out the hour. It is to impart uniformity of motion to this train of wheel-work that the pendulum is used.

Fig. 38 shows the mechanism by means of which the pendulum acts as a regulator. A toothed wheel, *R*, called a scape wheel, is connected with the train driven by the motor, and this scape wheel is checked by an anchor, *mn*, which is attached to the pendulum and vibrates with it. The anchor has two projecting points, *m* and *n*, called pallets, which engage alternately with the teeth of the scape wheel, in such a manner that only one tooth can pass at each swing

Limitation. What is isochronism? When are vibrations isochronal? Who discovered the pendulum, and when? (**55.**) What is the principal use of the pendulum? What is the motor in a clock? What is the use of the pendulum? *Explain the action of the pendulum as a regulator.*

of the pendulum. The motor turns the scape wheel in the direction of the arrow until one of the teeth comes in contact with the pallet, *m*, which stops the motion of the wheel-work till a swing of the pendulum lifts the pallet, *m*, from between the two teeth, when a single tooth passes and the wheel-work moves on until again arrested by the pallet, *n*, falling between two teeth on the other side. A second swing of the pendulum lifts out the pallet, *n*, suffers another tooth to pass, when the wheel-work is again arrested by the pallet, *m*, and so on indefinitely. The beats of the pendulum being isochronous, the interval of time between the consecutive escape of two teeth is always constant, and thus the motion of the wheel-work is kept uniform. The loss of force which the pendulum continually experiences, is supplied by the motor through the scape wheel and the anchor. This is called the sustaining power of the pendulum.

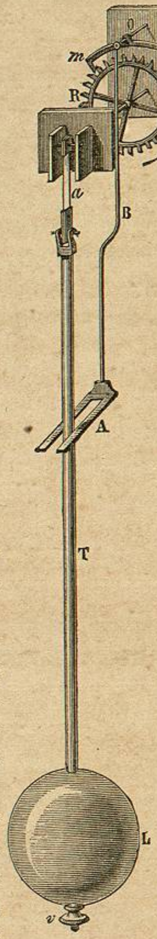

Fig. 38.

Owing to expansion and contraction from variations of temperature, the length of the pendulum varies, and according to the first law, its time of vibration changes. In nice clocks this change is compensated by a combination of metals. In common clocks, it is rectified by lengthening or shortening the pendulum by a nut and screw, shown at *v*, by means of which the lenticular bob may be moved up and down. In summer the pendulum elongates and the clock loses time, or runs too slow; this is rectified by screwing up the nut and shortening the pendulum. In winter the pendulum contracts and the clock gains time; this is rectified by unscrewing the nut and lengthening the pendulum.

What effect have variations of temperature on the pendulum? How are these effects compensated in nice clocks? How in common clocks? Why do clocks lose time in summer and gain time in winter?

In accordance with the principle enunciated in the fourth law, the pendulum has been used to determine the intensity of gravity at different points on the earth's surface. In this way it has been shown that the velocity acquired by a body falling in vacuum for one second, is $32\frac{1}{6}$ feet, in the latitude of the city of New York. It has been found by careful experiment that the length of a pendulum vibrating seconds in New York, is a little over 39 inches.

The length of the seconds pendulum at any place being constant, it has been taken as the basis of the English system of weights and measures, and from the English we have taken our own system.

The pendulum has been successfully employed by M. Foucault, a French physicist of our own day, to demonstrate the daily rotation of our globe. The details of his experiment are too abstruse to be given in this place.

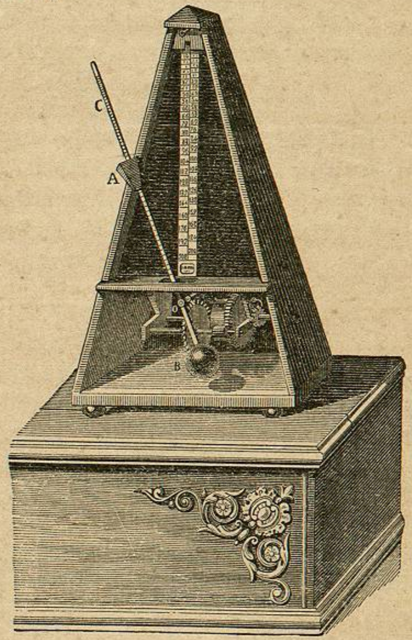

Fig. 39.

The Metronome.

56. The Metronome is a sort of pendulum employed by musicians and others to mark equal intervals of time. It is shown in Fig. 39. It consists of a pen-

What principle enables us to measure the force of gravity? How far does a body fall in one second? What is the length of a seconds pendulum in New York? Application to weights and measures? What application did Foucault make of the pendulum? (**56.**) What is a Metronome?

dulum CB, suspended at O. A weight, A, slides along the rod C, and may be set so as to make the vibrations as slow or as rapid as may be desired. The instrument is set by means of a scale, marked on the rod, so that any number of oscillations may be made in a minute. The pendulum is sustained by a coiled spring which sets in motion a train of wheels, somewhat in the manner of a clock. In the drawing the weight is set at 92, which shows that it is to make 92 oscillations per minute.

IV.—PRINCIPLES DEPENDENT ON MOLECULAR ACTION.

Molecular Forces.

57. BESIDES the forces which act upon bodies from without and at sensible distances, there is another class of forces continually exerted between the molecules of bodies, and acting only at insensible distances. These forces are called *Molecular Forces*, and are both *attractive* and *repellent*.

The molecules of bodies are held in equilibrium by these forces, and it is to them that are to be attributed many of the most important physical properties. The ultimate particles of bodies do not touch each other, being kept asunder by a force of repulsion, which we have said is in general due to heat; they are prevented from receding from each other too far by a force of attraction, and it is only when these forces just balance each other throughout the body, that it is in equilibrium.

When a body is compressed, the forces of repulsion are called into play, and, acting like coiled springs, they tend to restore the body to its primitive form. In like manner, when a body is elongated, or stretched, the forces of attraction are called into action and tend to restore the body to its primitive form.

Describe it. (**57.**) What are Molecular Forces? How divided? *How are molecules held in place? To what is the repellent force due? Explain the effects of compressing and stretching bodies.*

Cohesion.

58. COHESION is the force of attraction which holds the molecules of the same body together, as, for example, in a mass of iron, or of wood.

Cohesion differs from chemical affinity, which determines the molecules by uniting dissimilar atoms according to fixed laws. Chemical affinity unites atoms of carbon, oxygen, and hydrogen, to form molecules of sugar; but it is cohesion that unites the molecules of sugar into a solid body.

The strength of bodies depends upon *cohesion*. When a body offers a strong resistance to forces tending to tear it asunder, it is said to be tenacious; for example, iron or steel wires, and the like, are highly tenacious.

Adhesion.

59. ADHESION is the force of attraction which holds the molecules of dissimilar bodies together. Thus, it is adhesion which causes paint and glue to adhere to wood.

If two polished bodies are brought into contact, and pressed together, they will adhere with considerable force. If two plates of glass be ground so as to fit closely, and a little oil be interposed, it is very difficult to separate them. If two hemispheres of lead be pressed together, after having their plane surfaces well polished, they will adhere very strongly.

It is adhesion which renders it difficult to raise a wooden board from the surface of the water on which it floats. It is also adhesion between the particles of wood and water, that causes water to spread over a piece of wood upon which it is poured.

Solution is due to adhesion. Thus, when sugar dissolves in water, it is because the adhesion between the molecules of sugar

(**58.**) What is Cohesion? Example. *Difference between cohesion and chemical affinity? Illustrate.* When is a body tenacious? (**59.**) What is Adhesion? Example. *Explain adhesion of metallic surfaces. Of board to water. Explain the phenomenon of solution.*

and water is stronger than the cohesion between the molecules of sugar. If a liquid tends to spread itself over a solid body, it is said to wet it, as water upon glass. If it gathers in globules, it does not wet it, as quicksilver upon glass.

Capillary Forces.

60. Capillary Forces are molecular forces, exerted between the particles of a solid and those of a liquid. They are called capillary, because their effect is mostly observed in capillary tubes, that is, tubes of the diameter of a hair.

The following are some of the phenomena of capillarity:

1. When a body is plunged into a liquid which is capable of wetting it, as when a glass rod is plunged into water, it is observed that the liquid is slightly elevated about the body, taking a concave form, as shown in Fig. 40.

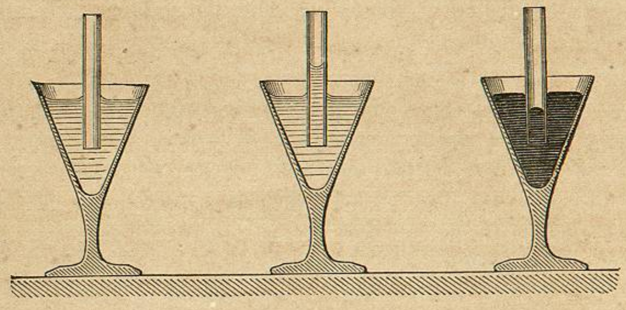

Fig. 40. Fig. 41. Fig. 42.

2. If a hollow tube is used instead of a rod, the liquid will also rise in the tube, as shown in Fig. 41. The smaller the bore of the tube, the higher will the liquid rise, and the more concave will be its upper surface.

(**60.**) What are Capillary Forces? Why so called? Explain the phenomenon observed when a glass rod is plunged in water. When a tube is plunged into water.

3. When a tube is plunged into a liquid which is not capable of wetting it, as when glass is plunged into quicksilver, the liquid is depressed both on the outside and on the inside, taking a convex surface, as shown in Fig. 42. The smaller the tube, the greater will be the depression, and the more convex will be the upper surface.

These capillary phenomena are due to the resultant action of the cohesion of the liquid and the adhesion of the solid and liquid. When the former predominates, the liquid is depressed in the tube. When the latter predominates, the liquid is raised in the tube.

Applications of Capillarity.

61. It is in consequence of capillary action that oil is raised through the wicks of lamps, to supply the flame with combustible matter. The fibres of the wicks leave between them a species of capillary tubes, through which the oil rises.

If a piece of sugar have its lower end dipped in water, the water will rise through the capillary interstices of the sugar and fill them. This drives out the air and renders the sugar more soluble than when plunged dry into water, in which case the contained air resists the absorption of water, and retards solution.

If a bar of lead be bent into the form of a siphon, and the short arm be dipped into a vessel of mercury, the mercury will rise into the lead by capillary action, and flowing over the edge of the vessel will descend along the longer branch and escape from the lower extremity. In this way the vessel may be slowly emptied of the quicksilver.

Many fluids may be drawn over the edges of the containing vessels by a siphon of candle-wicking or other capillary substance.

When a glass tube is plunged into mercury. Causes of the phenomena. (**61.**) Why does oil rise in a wick? Water in sugar? Explain leaden siphon. Explain siphon of wicking.

Absorption.

62. Absorption is the penetration into a porous body, of some foreign body, whether solid, liquid, or gaseous.

Carbon, in the form of charcoal, has a great capacity for absorbing gases. If a burning coal be introduced into a bell-glass, filled with carbonic acid, collected over mercury, the volume of the gas is diminished by being absorbed by the coal. It is found that the charcoal absorbs in this way thirty-five times its own volume of the gas. Charcoal also absorbs other gases in even still greater quantities.

Spongy platinum absorbs hydrogen so rapidly as to heat the platinum red-hot.

In vegetables and animals we have many examples of absorption. The roots of plants absorb from the earth the material necessary to the growth of the stem and branches.

In the animal world, absorption plays an important part in the process of nutrition and growth. Animal tissues also absorb solid substances. For example, workmen engaged in handling lead absorb through the skin and lungs more or less of this substance, which often gives rise to very serious diseases.

Imbibition.

63. Imbibition is the penetration of a liquid into a solid body.

Imbibition is an effect of capillarity, for the interstices between the molecules, by communicating with each other, form a mass of capillary tubes, into which the liquid penetrates by virtue of the capillary forces. Such is the cause of wood and earth absorbing water and other liquids. If a damp substance be placed in a dry and porous vessel, it

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(**62.**) What is Absorption? Examples. Carbon. Spongy platinum. Vegetables. Animals. (**63.**) What is Imbibition? What is the cause of imbibition? Examples.

will grow drier, whereas, if placed in a vessel which has no attraction for water, it will remain moist.

When vegetable and animal substances imbibe water, they generally augment in volume. This fact explains many phenomena of daily observation.

If a large sheet of paper be moistened, it increases in size, and again contracts when dried. This property is employed by draughtsmen to stretch paper on boards. The paper is moistened, and after being allowed to expand, its edges are glued to a drawing-board; on drying it is stretched, forming a smooth surface for drawing upon. The same property causes the papering of rooms to peel off the walls when exposed to moisture.

When a workman would bend a piece of wood, he dries one side and moistens the other. The side which is dried contracts, and the opposite side expands, so that the piece is curved. It is the imbibition of moisture that causes the wood-work of houses, furniture, &c., to swell and shrink with atmospheric changes, and which necessitates their being painted and varnished. Paints and varnishes, by filling the pores, prevent imbibition.

Imbibition makes ropes swell laterally, and thus, by increasing the circumference around which the fibres are twisted, the ropes are shortened. This shortening takes place with a force that may be employed to raise heavy weights. On the same principle new cloth shrinks on being washed, but it increases in thickness.

It is related that Pope Sixtus-Quintus, on the occasion of raising an obelisk, which he had caused to be brought from Egypt, issued an order that no one of the crowd should utter a word during the operation, on pain of death. As the operation was on the point of completion, the ropes stretched under the immense tension, and a failure was threatened. At this critical juncture the architect Zapaglia cried out from the crowd: "Wet the ropes!" It was done, and the obelisk was raised to its pedestal.

What is the effect of imbibition? On paper? Application. Effect on wood? Application. What is the effect on twisted fibres? On ropes? On new cloth? Relate the anecdote of Pope Sixtus-Quintus.

V.—PROPERTIES OF SOLIDS DEPENDENT ON MOLECULAR ACTION.

Tenacity.

64. TENACITY is the resistance which a body offers to rupture when subjected to a force of traction; that is, a force which tends to tear the particles asunder.

The tenacity of a body may be determined in pounds. For this purpose it is formed into a cylindrical form, having a given cross-section; its upper end is then made fast, and a scale-pan is attached to the lower end; weights are then placed in the pan until rupture takes place. These weights measure the tenacity of the body.

Metals are the most tenacious of bodies, but they differ greatly from each other in this respect. The following table exhibits the weights required to break wires of $\frac{655}{10000}$ of an inch in diameter, formed of the metals indicated:

Iron	549 lb.
Copper	302 "
Platinum	274 "
Silver	187 "
Gold	150 "
Lead	27 "

It has been shown by theory and confirmed by experiment, that of two cylinders of equal length and containing the same amount of material, one being solid and the other hollow, the latter is the stronger.

This latter principle is also true of cylinders required to support weights; the hollow cylinder is better adapted to resist a crushing force than the solid one of the same weight, and hence it is that columns and pillars for the support of buildings are made hollow. This principle also indicates that the bones and quills of birds, the stems of grasses and other plants, being hollow, are best adapted to secure a combination of lightness and strength.

(**64**) What is Tenacity? *How is it measured? What bodies are most tenacious? Examples. What is the form of greatest strength? Application to grasses, quills, bones, &c.*

Hardness.

65. HARDNESS is the resistance which a body offers to being scratched or worn by another. Thus, the diamond scratches all other bodies, and is therefore harder than any of them.

After the diamond come the sapphire, the ruby, rock-crystal, &c., each of which is scratched by the preceding one, but scratches the succeeding one.

Hardness must not be confounded with resistance to shocks or compression. Glass, diamond, and rock-crystal are much harder than iron, brass, and the like, and yet they are less capable of resisting shocks and forces of compression; they are more *brittle*.

An alloy or mixture of metals is generally harder than the separate metals of which it is composed. Thus, gold and silver are soft metals, and, in order to make them hard enough for coins and jewelry, they are alloyed with a small portion of copper. In order to render block-tin hard enough for the manufacture of domestic utensils, it is alloyed with a small quantity of lead.

The property of hardness is utilized in the arts. To polish bodies, powders of emery, tripoli, &c., are used, which are powders of very hard minerals. Diamond being the hardest of all bodies, it can only be polished by means of its own powder. Diamond-dust is the most efficient of the polishing substances.

Ductility.

66. DUCTILITY is the property of being drawn out into wires by forces of extension.

Wax, clay, and the like, are so tenacious, that they can easily be flattened by forces of compression, and readily wrought between the fingers. Such bodies are plastic. Glass, resins, and the like, only become tenacious when heated. Glass at high temperatures is

(**65.**) What is Hardness? What body is hardest? What bodies come next? *What are brittle bodies? What is the effect of alloying bodies? Explain the operation of polishing? How is the diamond polished? What is the best polishing substance?* (**66.**) What is Ductility? *Give examples of plastic bodies?*

so highly ductile, that it may be spun into fine threads and woven into fabrics. Many of the metals, as iron, gold, silver, and copper, are ductile at ordinary temperatures, and are capable of being drawn out into fine wires, by means of wire-drawing machines.

The following metals are arranged in the order of their ductility: *platinum, silver, iron, copper, gold, zinc, tin, lead.*

Malleability.

67. MALLEABILITY is the property of being flattened or rolled out into sheets, by forces of compression.

This property often augments with the temperature; every one knows that iron is more easily forged when hot than when cold. Gold is highly malleable at ordinary temperatures. Gold is reduced to thin sheets by being rolled out into plates by a machine; these plates are cut up into small squares, and again extended by hammering until they become extremely thin. They are then cut up again into squares, and hammered between membranes, called gold-beater's skins. By this process gold may be wrought into leaves so thin, that it would take 282,000, placed one upon another, to make an inch in thickness. These leaves are employed in gilding metals, woods, paper, and the like. Silver and copper are wrought in the same manner as gold.

The following metals are amongst the most malleable under the hammer: *gold, silver, platinum, iron, tin, zinc, copper, lead.*

When metals are alloyed, they are generally harder and less malleable, as well as less ductile.

Is gold ductile? When? Give examples of ductile metals. (**67.**) What is Malleability? *Effect of temperature? How is gold formed into sheets? What is the order of malleability of metals? Effect of alloying.*

CHAPTER II.

MECHANICS OF LIQUIDS.

I.—GENERAL PRINCIPLES.

Definition of Hydrostatics and Hydrodynamics.

68. THE Mechanics of Liquids is divided into two branches: HYDROSTATICS, which treats of the laws of equilibrium of liquids, and HYDRODYNAMICS, which treats of the laws of motion of liquids.

Properties of Liquids.

69. The following properties are common to all liquids:

1. The molecules of liquids are extremely movable, yielding to the slightest force.

There is very little cohesion between the molecules of liquids, whence their readiness to slide amongst each other. It is to this principle that they owe their fluidity.

2. Liquids are only slightly compressible.

Liquids are so slightly compressible, that for a long time they were regarded as absolutely incompressible. In 1823, ERSTED demonstrated, by an apparatus which he contrived, that liquids are slightly compressible. He showed that for a pressure of one atmosphere, that is, of 15 lbs. on each square inch of surface, water is compressed the $\frac{49}{1000000}$th of its original volume. Slight as is

(**68.**) Define Hydrostatics. Hydrodynamics. (**69.**) What is the first property of Liquids. *Illustrate.* Second property? *Illustrate.*