NATURAL PHILOSOPHY FOR SCHOOLS

BY D^r. LARDNER

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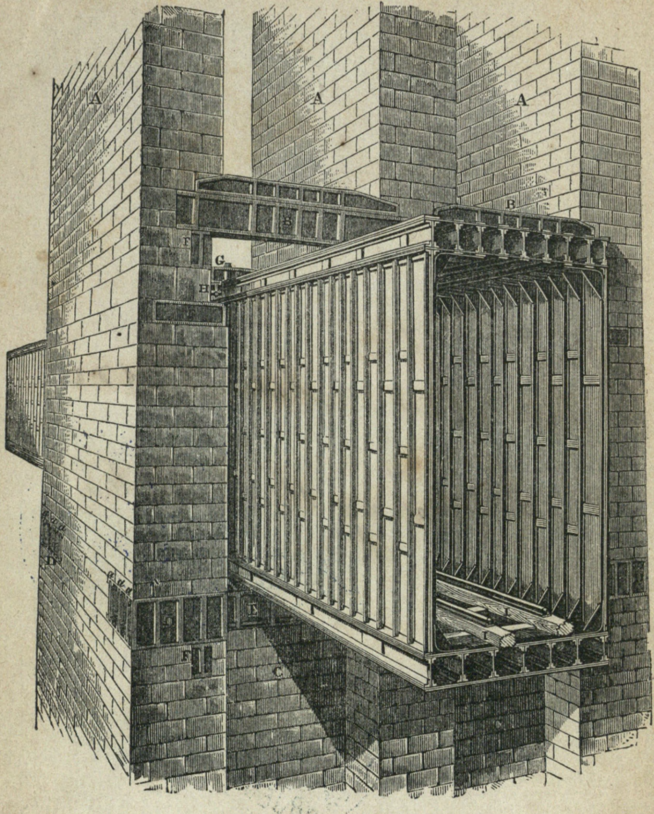

BRITANNIA TUBULAR BRIDGE.

NATURAL PHILOSOPHY

FOR

SCHOOLS.

BY

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WITH THREE HUNDRED AND TWENTY-EIGHT ILLUSTRATIONS.

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PREFACE.

This volume has been compiled to supply the want felt by a large number of teachers in public and private schools of a Class Book for Junior Students. Its purpose is to convey, in clear and concise terms, general notions of all the principal divisions of Physical Science, illustrated copiously by diagrams, showing the forms and arrangement of apparatus and the manner of performing the most important experiments.

Each of the subjects briefly explained here is fully developed in all its details, and more amply illustrated, in the corresponding parts of the "Hand Book of Natural Philosophy," which should always be in the hands of the teacher, who, by oral instruction, will then be enabled to develop each point, and illustrate it more or less fully, according to the capacity of the pupil.

It may be hoped that this volume may be the means of extending instruction in the first notions of Physics into Ladies' Schools. Female teachers in general will find even the Hand Book easily intelligible, and by it will be enabled to use the present volume for the instruction of their pupils.

The Table of Contents is so composed that the teacher can form from it Questions for the examination of his Class, the Answers to which will be found in the corresponding paragraphs of the volume.

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NATURAL PHILOSOPHY FOR SCHOOLS.

CHAPTER I.

GENERAL PROPERTIES OF BODIES.

1. The bodies which compose the world around us consist of a substance called *matter*, and hence the familiar terms, *material universe*, *material world*, *material things*, and so on.

2. Bodies exist in three different states, *solid*, *liquid*, and *aeriform* or *gaseous*.

Stone, wood, and metal, are solids; water, oil, and wine, liquids; and the atmosphere an aeriform or gaseous body.

3. Liquids and gases are expressed by the common name of *fluids*. They differ from each other in this, that liquids are incompressible fluids, while gases are highly compressible.

4. Matter has certain qualities some of which are inseparable from it, and others merely incidental to it in particular states.

5. Its general properties are *impenetrability*, *divisibility*, *porosity* and *density*, *compressibility* and *contractibility*, *elasticity* and *inactivity*.

6. Its special qualities found in some bodies and not in others, and existing in infinitely various degrees, are *hardness*, *softness*, *brittleness*, *flexibility*, *malleability*, *ductility*, *tenacity*, and various others.

7. The physical changes to which bodies are subject are called *phenomena*, a Greek word signifying "appearances."

8. *Physical agencies* are the causes which produce phenomena when these causes are known.

9. *Hypotheses* are the supposed causes of phenomena whose real causes are not yet discovered.

10. A *Theory* is an hypothesis which explains any collection of phenomena supposed to arise from the same cause acting under various conditions.

11. When phenomena of any class are produced in a regular

manner so that their recurrence under given conditions can be certainly foreseen, they are said to constitute a *physical law*.

Thus, for example, that all bodies which are not supported will descend in perpendicular lines to the surface of the earth; that all liquid bodies will settle when at rest into such a position that their surface will be level; that all aeriform bodies will, when submitted to compression, contract their dimensions; and when relieved from that compression, will expand to their former dimensions; are severally physical laws.

12. It is demonstrated by a variety of phenomena, and by reasoning upon them, that all bodies consist of *ultimate atoms* which are infinitely too minute to be discoverable by the senses, even when aided by most powerful microscopes, but the existence of which is nevertheless ascertained by their effects. These atoms are combined together by a certain attraction so as to form particles, which are still so minute as to escape the sense, and which are called *molecules*.

These molecules are the immediate component parts of bodies.

13. All the molecules of the same body are alike, but the molecules of different bodies are different.

Thus, the molecules which constitute water are different from those which constitute air, and from those which constitute stone or metal.

14. All bodies are susceptible of divisibility without any practicable limit, since by no known means can they be ever separated into their ultimate molecules. So long as the molecules themselves are not resolved into their component atoms, the process is called *divisibility*, but when through suitable agency the molecules constituting any body are resolved into their constituent atoms, the process is called *decomposition*.

Thus, for example, water may be divided without limit by being diffused in the thinnest imaginable stratum upon any surface, and still more minutely by evaporation; but its particles or molecules thus separated will still retain all the properties of water, and when these molecules are reunited, the liquid will return to its original state.

15. But if by any agency the molecules of water themselves are resolved into their constituent atoms, two gaseous bodies will be produced, one called *hydrogen*, and the other *oxygen*; the atoms of which, when united, constitute the molecules of water. This process is totally different from mere divisibility, and is called decomposition. Such phenomena as decomposition and recomposition belong not to Natural Philosophy, but to Chemistry: divisibility, on the other hand, is a property which falls within the proper limits of Natural Philosophy.

16. The molecules which compose a body are never in absolute contact. There are always more or less unoccupied spaces between them. These spaces are called *pores*.

17. The *density* of a body is the closeness or proximity of its

molecules, and *porosity*, on the other hand, the greater or less unoccupied space intervening between them.

Bodies are more or less dense according to the number of molecules included within a given space.

It is evident that as density increases porosity diminishes.

18. *Impenetrability* is the quality of matter in virtue of which two bodies cannot at the same time occupy the same space.

The examples of apparent penetrability are cases of mere displacement. When a body is plunged in water it does not penetrate the water, but displaces that portion of it whose place it occupies. In like manner, when a body passes through the air, it pushes that fluid out of its way.

19. That air, light and attenuated as it is, is impenetrable, is proved by the familiar experiment of inverting a common drinking glass and plunging its mouth in water. The water will in this case be excluded from the glass, notwithstanding the pressure produced by the weight of the external water, because the air which fills the glass is still there, and its presence is incompatible with that of any other body.

20. If a body be submitted to a compressing force, its component molecules will be forced into closer contiguity, and the bulk of the body will be diminished. This property is called *compressibility*.

21. When the body is released from the force which thus compresses it, the molecules which had been pressed together will often again recoil from one another, so that the body will resume its former dimensions with a certain force. This property is called *elasticity*.

22. The unlimited divisibility of matter may be shown by a multitude of examples.

23. If marble be reduced to fine powder by the process of grinding or pulverisation, the particles, though very minute, will still be mere blocks of marble, and can be ascertained to be such by the microscope. If gold be rubbed upon a touch-stone, visible, though very minute, particles will be left upon the stone. Glass may be drawn by means of the blow-pipe into threads whose diameter does not exceed the 2000th part of an inch.

24. Dr. Wollaston produced platinum wire, 30000 pieces of which placed side by side would not measure an inch in breadth. Newton showed that the film of water at the upper surface of a soap bubble has a thickness of little more than the three millionth part of an inch. The wings of certain insects are so thin, that 50000 of them piled in a heap would not have a quarter of an inch in height. In the fabrication of gold lace, an ounce of gold is divided into 430000 millions of parts, each still possessing the characteristics and qualities found in the largest masses of metal, having solidity, texture, and colour; resisting the same chemical agents, and entering into combination with the same substances. A drop of blood suspended from the point of a cambric needle contains three million red discs, from which it derives its colour.

25. Ehrenberg has proved the existence of certain animalcules so minute,

that millions of them collected into a single mass would not exceed the bulk of a grain of sand, and thousands might swim side by side through the eye of a cambric needle. The shells of such animalcules in the fossil state constitute the substance of certain slates found at Bilin, in Bohemia, a cubic inch of which is computed to contain 41000 millions of such shells; and since a cubic inch of the slate weighs only 220 grains, it would follow that 187 millions of these shells would weigh only a grain.

26. A single grain of the blue salt, called the sulphate of copper, dissolved in a gallon of water, will render the whole perceptibly blue. A single grain of musk will exhale odorous particles, which will impregnate the atmosphere of a large room perceptibly for a quarter of a century and upwards without suffering considerable loss of weight. A thread of spider's web four miles long will weigh little more than a grain. A scarcely perceptible particle of strychnine will render a pint of water perceptibly bitter; and a single grain of salt of silver will render a gallon of water perceptibly sweet.

27. Density and porosity may be illustrated by the following experiments:—

Mercury and water may be forced through the pores of wood. In the celebrated Florentine experiment, water was enclosed in a globe of gold; when the globe was compressed the water oozed through the pores of the gold, and appeared as a dew upon its external surface.

28. Water is rendered clear by passing it through the pores of certain sorts of stone, the process being called *filtration.* Chalk is more porous than marble, though consisting of the same constituents. Stones taken from great depths in the bottom of the sea are found to be impregnated with water. Water percolates through the sides of caverns and grottoes, and being impregnated with calcareous matter forms stalactites or pendulous particles, presenting curious appearances with which every one is familiar.

29. *Compressibility* may be illustrated by numerous examples.

Wood is hardened by severe compression to form the wedges of railway chairs. The most solid stone when placed under heavy weights is found to be compressed; columns which sustain incumbent weights in architecture are examples of this. Metals are compressed by percussion and hammering, so as to be rendered more compact and dense. Liquids are in general less easily compressed than solids, and are regarded as practically incompressible. Strictly speaking they are susceptible of some compression, however, as was proved by a celebrated experiment, in which water submitted to a mechanical pressure of 15 lbs. per square inch of its surface was found to be diminished in volume by 45 parts in a million. Water enclosed in a piece of cannon and submitted to mechanical pressure of 15000 lbs. per square inch was diminished by a 20th part of its bulk. The cannon was burst by its reaction.

30. Gaseous bodies are eminently compressible, as will be more fully proved hereafter. Elasticity, or the force by which a body compressed, or otherwise changed in its form, resumes its original dimensions or form, is illustrated by the following experiments.

An ivory ball let fall upon a hard surface smeared with oil or colouring matter will be flattened at the point of contact, as will be proved by the extent of its surface coated with oil. If it be let fall from different heights, the extent of the flattened part will be greater the greater the height. A steel spring bent recovers its form with a force equal to that which bent it.

31. Although all bodies are more or less elastic, different bodies possess the quality in different degrees.

Elasticity is also manifested by the torsion or twisting of a thread or wire. When disengaged, it will untwist itself, and then again twist itself. This is called the *elasticity of torsion.*

32. *Dilatability* and *Contractibility* are also universal properties of bodies, in virtue of which they enlarge their dimensions when heated, and contract them when cooled.

Bars of metal alternately heated and cooled, will alternately expand and contract. This property is sometimes used as a mechanical agent. Thus the walls of a building when threatening to fall by the pressure of the roof upon them, have been drawn together by passing bars across them with nuts screwed upon them outside the walls. The bars being heated expand, and the nuts being then screwed up to the wall, the bars are cooled, and by their consequent contraction draw the walls together, and this operation being frequently repeated, the walls are at length restored to the perpendicular. This process was applied with great success to the walls of the Conservatoire des Arts et Métiers of Paris by Molard.

33. Since there is a continual change of temperature in all bodies, there is also a continual change of magnitude. The bodies around us are, therefore, constantly swelling and contracting under the vicissitudes of heat and cold. They grow smaller in winter, and dilate in summer. They swell on a warm day, and contract on a cold one. In warm weather the flesh swells, the vessels appear hard and plump, and the skin distended. In cold weather, when the body has been exposed to the open air the flesh contracts, and the skin shrivels.

34. *Inertia* is a negative quality universally appertaining to matter. It is the Latin word for "inactivity," and implies the total absence of all power in a body to change its state, whether of rest or motion. If a body be at rest it cannot put itself in motion, and if in motion, it cannot reduce itself to rest, nor can it change the motion it has either in its velocity or in its direction. Whenever any such change takes place, it must arise from the operation of some external cause, independently of the body.

35. Since all bodies which are in motion on the surface of the earth have a tendency to become gradually retarded, and at length come to rest, we are led naturally to think that they have a tendency more to rest than motion; but this is an error. Their retardation and ultimate repose is not due to any property in the bodies themselves, but to the resistances which are opposed to their motion by the bodies with which they are in contact. Thus all bodies whatever which are around us, or accessible to us, must move through the air, which offers a resistance to the motion

of the body. Bodies, also, in general, move upon some supporting surfaces, as carriages or sledges do upon a road or railway; and, however smooth and level such surfaces may be, they always produce a resistance due to friction.

36. It is therefore friction and the resistance of the atmosphere which cause the general retardation of the motions universally observed, and the proof of this is, that bodies which move in a vacuum continue their motions until they are stopped by friction; and the more the friction is diminished, the less will be the resistance to the motion of bodies, and the less will be its retardation. The friction on a railway is less than upon a road, and, consequently, bodies moving on a railway will be much less retarded than those which move on a road.

37. The quality of inertia is manifested by the tendency which all bodies in motion have to retain their motion, and the resistance which they oppose to anything which has tendency to stop such motion.

If a horse or vehicle be suddenly stopped, the rider or the passengers still retaining the motion they had will be thrown *forwards*, and if a horse or vehicle being at rest be suddenly started forwards, the rider or passengers will be thrown *backwards*. If a person leap from a carriage in motion, he will fall, when his feet touch the ground, in the direction in which the carriage is moving. In coursing, the hound which pursues the hare, being comparatively a heavy body, cannot suddenly arrest its course, because by its greater inertia it has a tendency to move onwards in the same straight line; but the hare, a comparatively light body, first gradually retards its motion, so as to diminish its inertia, and at the moment when the hound is in the act of seizing it, dexterously turns at an acute angle to its former course, leaving the hound propelled forwards in the direction it was previously moving. Thus, if the hound pursues the hare from A towards B, (*fig.* 1.) the hare at C suddenly doubles, turning back from C to D, while the hound, carried onwards by its inertia, is unable to stop itself until it arrives at B, the hare having meanwhile arrived at D. By this trick the hare has gained upon the hound the distance B D.

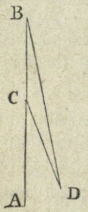


Fig. 1.

CHAP. II.

SPECIAL PROPERTIES OF BODIES.

38. The properties of bodies explained in the preceding paragraphs are universal, although some of them exist in different bodies in different degrees. We shall now notice some properties which are *special*.

39. *Hardness* differs from density. Glass, for example, is harder

than gold or platinum, though less dense than either. Glass will scratch these metals. Again, gold and platinum, though more dense than iron and zinc, are not so hard. Some metals are capable of being rendered hard by certain processes. Thus, when iron is heated and suddenly cooled, by being plunged in water, it becomes harder than glass, but if cooled gradually becomes soft and flexible.

40. *Flexibility* and *brittleness* exist in an infinite variety of degrees in different bodies. A body is flexible when it will bend without breaking, brittle when it breaks rather than bends.

Brittleness is connected with hardness, but is not identical with it, and is not inconsistent with certain forms of elasticity. Glass, which is highly elastic, is also the most brittle of bodies. The same body may be rendered more or less brittle by the application of heat and cold.

41. *Malleability* is the quality in virtue of which bodies may be reduced to thin plates, either by the hammer or by pressure between rollers, by processes of extensive use in the arts.

In large iron works lumps of iron rendered white hot, but not yet melted, are taken from the furnace, stuck upon the end of a long bar of iron, and placed under a sledge hammer of enormous weight, which rapidly striking, reduces them to an elongated form approaching that of a bar. The metal, still red hot, is then pushed between rollers formed in the shape of the transverse section of the rails used in railways. When drawn between these rollers the rail has acquired its proper form, but it is still red and soft, and when received from the rollers is so flexible that it bends by its own weight like a rod of wax. It is then laid on a flat surface where it cools and hardens, and assumes the condition of the rails on which we travel.

42. *Annealing* is the process of cooling by which substances are rendered malleable.

43. *Welding* is the process by which malleable metals are united together by hammering them when red hot. The particles thus driven into intimate contact cohere, forming a single mass. This process may in some cases be applied to unite together different metals.

44. *Ductility* is the property in virtue of which metals allow of being wire-drawn. It is not identical with malleability, since the same metals are not always ductile and malleable in the same degree. Iron is more ductile than malleable; tin and lead on the contrary are highly malleable, but very little ductile.

45. *Tenacity* is the property in virtue of which a body resists the separation of its parts by a force which stretches it.

Bodies may have great tenacity and at the same time great brittleness. A thin rod of glass will sustain an immense weight suspended at its lower end, while the slightest force applied transversely to it will break it.

CHAP. III.

FORCE AND MOTION.

46. A *force* is a physical agency, which either imparts motion or produces pressure, or causes both of these effects. When forces produce pressure they are easily measured by naming the weight which would produce a like pressure.

If two forces act at the same time upon the same point, and in the same direction, the effect will be equal to their sum.

Thus, if one be equivalent to a weight of 10 lbs., and the other to a weight of 20 lbs., the combined effect will be that of a weight of 30 lbs.

But if they act in opposite directions then the lesser will neutralise a portion of the greater, and their combined effect will be that of their difference.

Thus, if a force of 10 lbs. act against a force of 20 lbs., the combined effect will be that of a force of 10 lbs. acting in the direction of the force of 20 lbs.

47. If a force put a body in motion, its effect will be determined by the velocity imparted to the body. The velocity is measured by the space through which the body would move in any given time, as, for example, in one second: and the more intense the force is which acts upon the body, the greater will be this space.

If two forces act upon the same body in the same direction, one of which would impart to it a velocity of 20 feet per second, and the other 10 feet per second, the body will move with a velocity of 30 feet per second; but if the two forces thus applied act in a contrary direction, then the body will move with a velocity of only 10 feet per second, the lesser force depriving the greater force of part of its effect.

48. If two equal forces act at the same point, and in contrary directions upon a body, they will neutralise each other, and neither motion nor pressure will be produced. The forces in this case are said to be in *equilibrium*, and it may be stated still more generally, that any number of forces acting at the same time upon a body in such a manner as to impart no motion to it, are said to be in equilibrium. It is sometimes stated in this case that the body which is placed under the operation of such forces is in equilibrium.

49. If two forces act upon a body at the same point, A, *fig.* 2., and in different directions, A X and A Y, their combined effect is the same as that of a single force acting in a certain intermediate direction A D.

The manner in which this intermediate direction is determined is as follows. Take upon A X a length A C, consisting of as many inches as there are pounds in the force directed from A to X, and upon A Y take A B, consisting of as many inches as there are pounds in the force directed from A to Y, and from B and C draw lines parallel to A X and A Y, so as to form the parallelogram A B D C; then draw A D, the diagonal of this parallelogram. The combined effect of the two forces will be the same as that of a single force directed from A to D, consisting of as many pounds as there are inches in A D.

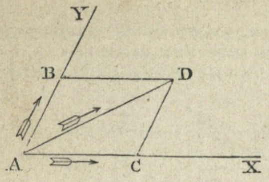


Fig. 2.

50. We have here supposed the two forces acting at A to produce a pressure represented by an equivalent weight; but if, instead of producing pressure, the forces were to impart motion to the body, the same principle would be applicable; but in that case the lengths A C and A B would be spaces through which the body would be moved in one second by the separate actions of the two forces, and A D would be the line through which it would be moved in one second by their combined action.

51. This proposition has obtained great celebrity in mechanical science from its utility in all investigations, theoretical and practical, and is known as the *parallelogram of forces.*

52. The force expressed by the line A D is called the *resultant*, and those expressed by the lines A B and A C the *components*, and the principle of the parallelogram of forces is shortly stated by saying that *the resultant is mechanically equivalent to its components, and the components mechanically equivalent to the resultant.*

53. When two forces are combined to produce a single force they are said to be compounded, and the process is called the *composition of forces;* but since the components are mechanically equivalent to the resultant, we may also imagine a single force to be replaced by two forces whose combined actions are equivalent to it, and this way of considering the principle is called the *resolution of forces.*

54. An infinite variety of pairs of components may have a common resultant, and on the other hand, the same force may be resolved into an infinite variety of pairs of forces.

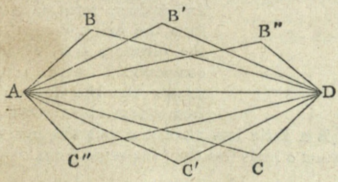


Fig. 3.

Thus A D (*fig.* 3.) will represent the common resultant of the forces A B and A C, and of A B' and A C' of A B" and A C", and so on.

55. Numerous examples may be given illustrating the composition and resolution of forces and motion.

56. A swimmer who crosses a rapid stream is moved directly across by the action of his members, and carried at the same time downwards by the stream. Instead of proceeding, therefore, from P to M (*fig.* 4.), as he would

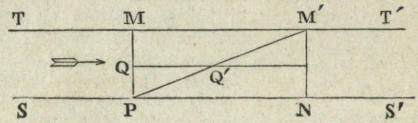


Fig. 4.

do if there were no current, he is carried along the diagonal from P to M′; the stream running in the direction of the arrow, and S S′ and T T′ representing the banks. If he desire, therefore, to proceed directly across the stream, from P to M, he should endeavour to swim from P to O (*fig.* 5.).

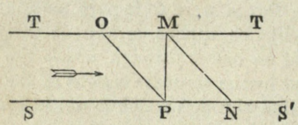


Fig. 5.

57. A vessel impelled at the same time by wind and tide takes an intermediate direction between the two directions which it would separately receive from each.

58. Billiard playing depends altogether on the principles of the composition and resolution of motion. The ball P (*fig.* 6.), striking the cushion at O in the direction P O, would have its motion resolved into two by the reaction of the cushion, one in the direction of O C, along the cushion, and the other O B, which would be destroyed by the reaction of the cushion; and if the ball and cushion were inelastic, the ball would move from O to C; but in consequence of the elasticity, the ball and cushion react, so as to give the ball a motion in the direction O B′, which, compounded with O C, causes the ball to move from O towards D. Owing to the imperfect elasticity, O B′ is a little less than O B, and the ball is reflected at an angle with the cushion a little less than the angle P O M.

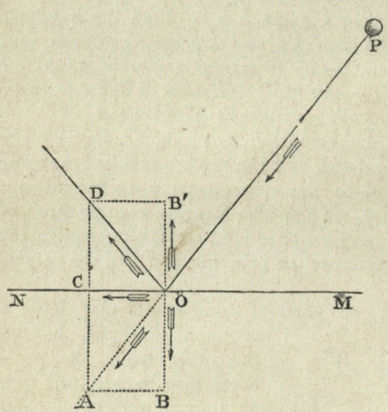


Fig. 6.

59. Motion is distinguished into *absolute* and *relative*.

If a man walk on the deck of a ship from stem to stern, he has a motion relative to the deck measured by the space upon it along which he walks in a given time; but while he thus walks, the ship and its contents, including himself, are carried in the opposite direction. If it should so happen that his own progressive motion from stem to stern is exactly equal to that of the ship in the contrary direction, he will be at rest in relation to the surface of the sea. Thus he may be said to be in absolute rest, but in relative motion.

60. Many feats in gymnastic exhibitions are explained by the principles of the composition and resolution of motion.

Thus an exhibitor standing on the saddle leaps over a cord under which the horse passes, returning to the same point which he left after the horse has passed under the cord. This feat is accomplished on the part of the rider by springing directly upwards without giving himself any forward motion, since he has had already all the necessary forward motion in common with the horse. When he springs upwards, therefore, the upward motion received from the reaction of the saddle is combined with the forward motion which his body already has; and the consequence is, that while he rises vertically upward, his body also goes forward, exactly as fast as the horse, and by the time he has descended to the level of the saddle, the saddle has advanced exactly to the part at which his feet arrive. (*Fig.* 7.)

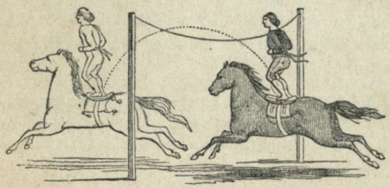


Fig. 7.

61. When a mass of matter is in motion with a certain velocity, it is animated by a certain force with which it would strike any object it encounters, and this force will depend upon the quantity of matter in the moving mass, and upon the velocity with which it moves. If two equal masses move with the same velocity, they will have the same *momentum* or *moving force*. If they move with different velocities, they will have a moving force exactly proportional to these velocities.

62. If two unequal masses move with the same velocity they will have a moving force exactly proportional to their masses.

Thus, for example, if two balls, each weighing 1 lb., move, one with the velocity of 10 feet, and the other with a velocity of 20 feet per second, the latter will strike a body with twice the force of the former.

63. If two balls, one which weighs 1 lb. and the other 2 lbs., be moved with the velocity of 10 feet per second, that which weighs 2 lbs. will strike an object with twice the force of that which weighs 1 lb., but if the balls be not only unequal in weight, but also moved with unequal velocities, then their forces will be estimated by multiplying their weight by their velocities.

Thus, if one ball weigh 3 lbs. and move with a velocity of 10 feet per second and the other weigh 6 lbs. and move with a velocity of 20 feet per second, the force of the former will be to the force of the latter in the proportion of 30 to 120, or of 1 to 4.

64. Let a cannon ball and a musket ball be projected with the same velocity, the force of the former will be greater than the force of the latter in the exact proportion of their respective weights.

65. When two bodies strike each other, whatever motion the one loses the other gains. This must necessarily be the case, inasmuch as, in consequence of the nature of inertia, no force can be either acquired or destroyed upon the whole; the motions, however, being understood to be estimated all in one direction. This principle is generally expressed by stating that *action and reaction are equal and contrary*.

Thus, if two bodies M, M′ (*fig.* 8.) be moving in the same direction, and M overtaking M′ strike it, the two bodies then coalescing, M will impart to M′ a certain force, and will itself lose precisely the same force, so that the sum

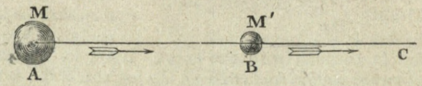


Fig. 8.

of the forces will be the same as before, but will be distributed between the two bodies differently. In this case the communication of force by M to M′ is called the *action of* M *upon* M′, and the loss of force which M sustains is said to arise from *the reaction of* M′ *upon it.*

66. It must not be understood, however, notwithstanding the general adoption of these terms, that there is any real action whatever on the part of the one body or the other, any such action being totally incompatible with the property of inactivity or inertia. The term action, therefore, should be understood in this case in a qualified sense, as merely expressing the acquisition of force by the one body and its loss by the other.

67. If the two bodies M, M′ (*fig.* 9.) move in contrary directions, and coalesce, M′ will destroy so much of the moving force of M as is equal to its

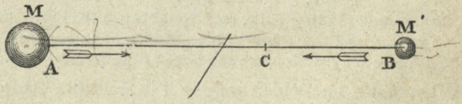


Fig. 9.

own force in the direction B A, and the two masses will move on together in the direction A B, with the difference of the forces which they had on coalescing. In this case, by the action of M upon M′, not only all the force which M′ has in the direction B A is destroyed, but it receives a new force in the direction A B. In like manner M not only loses an amount of force equal to that which M′ had in the direction B A, but also so much force as it has imparted to M′ in the direction of A B.

68. Numerous examples may be given of the application of this principle of action and reaction.

69. If two railway trains moving in a contrary direction at twenty miles an hour come into collision, the shock will be the same as if one of them being at rest were struck by the other moving at forty miles an hour.

70. If two steamboats of equal weight approach each other, one moving

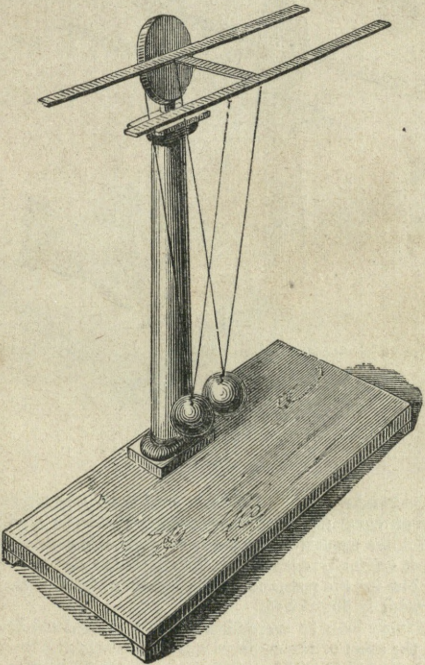


Fig. 10.

at twelve miles an hour, and another at fifteen, each will suffer a shock from the collision the same as if it were struck by the other moving at twenty-seven miles an hour.

71. In the combats of pugilists the most severe blows are those struck fist against fist, for the force suffered by each is then equal to the sum of the

forces exerted by the two arms. Skilful pugilists avoid such collisions, since both suffer equally, and more severely.

72. When the bodies which strike each other are elastic, the forces with which they recover their figures after compression are combined with the ordinary effects of action and reaction in the case of inelastic bodies. Some remarkable effects ensue from this cause, which may be illustrated by elastic balls of ivory like billiard balls suspended in contact, as shown in *fig.* 10.

If the ball A be raised from its position, as shown in *fig.* 11., and be let fall

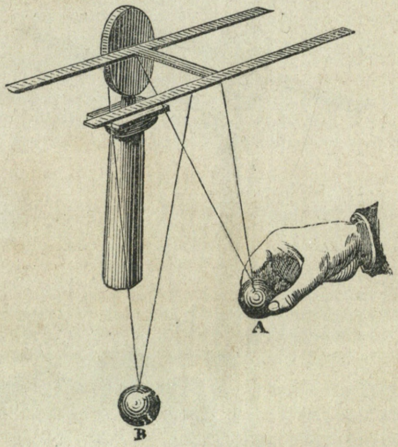


Fig. 11.

against B, the two balls will interchange conditions, A coming to rest, and B flying off to an equal distance in the contrary direction; B will then return upon A, and a like result will ensue, A in its turn rising nearly to the point from which it originally descended. This alternate motion would continue indefinitely but for the resistance of the air, by which the range of the vibration is gradually diminished.

If several ivory balls be suspended, as in *fig.* 12., and one be drawn aside and let fall, the effect of the collision will be transmitted through the series to the last ball, which will be affected exactly as if it were immediately acted upon by the first. Each of the intermediate balls in this case, being equally affected in opposite directions by the reaction of the contiguous balls in recovering their figures, will remain at rest, and the extreme balls alone will alternately rise and fall until reduced to rest by the resistance of the air.

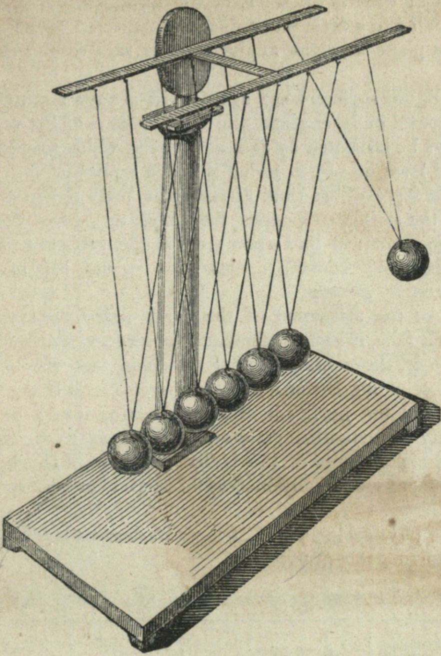


Fig. 12.

CHAP. IV.

GRAVITY.

73. When a body is suspended by a thread or wire or placed upon a horizontal plane, it will stretch the wire and press upon the plane with a certain force, and this force will be greater or less exactly in the proportion in which the mass of the body is greater or less.

If the body be not suspended or supported, it will descend in the exact direction of the string or wire which would have suspended it, or what is the same, in the direction of a line which is perpendicular to a level plane. This direction is called *the vertical line*, and a plane at right angles to it is said to be *level* or *horizontal*.

74. A liquid surface when at rest will always assume the form of a horizontal or level plane, and the direction of the vertical line will always be indicated by that of a string which supports a body suspended from it. Such string is called a plumb-line.

75. The force which thus attracts the body downwards, which stretches the string, or presses the plane, or causes the body to descend in a vertical line when free, is the attraction which the mass of the earth beneath exerts upon it, and this attraction is called *terrestrial gravity*.

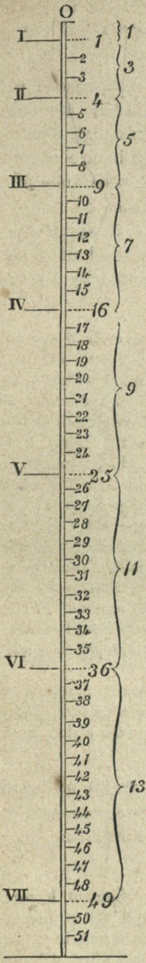
76. Since the attraction of the earth acts constantly upon a body which falls, it imparts from one moment to another increased velocity to it, the consequence of which is, that the motion of a body in descending is continually *accelerated*, and if the resistance of the air did not modify it, this acceleration would be uniform, the velocity imparted being always proportional to the time of the fall. The consequence of this is that the body in falling descends through spaces continually increasing in each successive second of time.

77. The physical law which governs its descent is fully expressed in the following table.

Tabular Analysis of the Motion of a falling Body.

Number of Seconds in the Fall, counted from a State of Rest.	Spaces fallen through in each successive Second.	Velocities acquired at the End of Number of Seconds expressed in First Column.	Total Height fallen through from Rest in the Number of Seconds expressed in First Column.
1	1	2	1
2	3	4	4
3	5	6	9
4	7	8	16
5	9	10	25
6	11	12	36
7	13	14	49
8	15	16	64
9	17	18	81
10	19	20	100

Although all the circumstances attending the descent of bodies falling freely are included with arithmetical precision in the above table, we may nevertheless render it more easy to obtain a clear conception of these important physical phenomena by the annexed diagram, in which the divided scale represents the vertical line along which the body is supposed to fall, O being the point from which it commences its descent. The points which it successively passes at the termination of 1, 2, 3, 4, 5, 6, and 7 seconds respectively are marked I, II, III, IV, V, VI, VII. The figures of the scale indicate the total heights through which the body has fallen at the end of each successive second, the unit being the height through which the body falls in the first second. The spaces included between brackets on the right of the



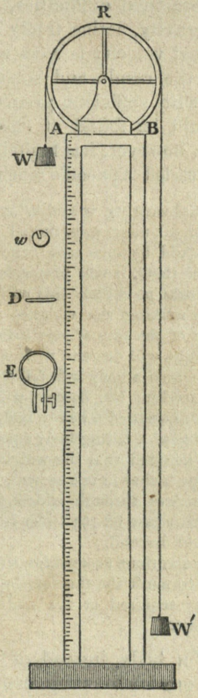


Fig. 13.

diagram are those through which the body falls in each successive second. It will then be apparent, first, that the body is accelerated in its motion, inasmuch as the spaces through which it falls in each successive second are evidently increasing; secondly, that the space through which it falls in any number of seconds is expressed by the square of this number, the unit being the space fallen through in the first second; thirdly, that the spaces fallen through in each successive second are expressed by the odd numbers with reference to the same unit.

78. A direct experimental verification of the results exhibited in the preceding table and diagram would be attended with several practical difficulties. The heights through which a body falls by gravity, acting freely in several seconds, are considerable, and a great velocity is soon acquired. The resistance of the air disturbs the result, and some difficulty would be found in observing, with sufficient precision, the points at which the falling body would be found at each successive second of time. This difficulty, however, has happily been surmounted by a simple contrivance called Atwood's machine (*fig.* 13.).

Two equal weights, W and W′ are attached to the ends of a string which passes over a pulley constructed so as to have very little friction. These weights would balance each other, but if a very small weight *w* be placed upon one of them, it will preponderate and will descend, drawing the other up. The rate at which this will descend can be rendered as slow as is desired by making the weights proportionably small. Thus if *w* be the 100th part of the sum of the three weights W, W′ and *w*, then the preponderating weight will descend with a velocity not more than the 100th part of that with which a body will fall freely, but in all other respects the circumstances attending the descent will be absolutely the same as those which attend the descent of a heavy body falling freely. In short, the phenomena will be those of a falling body upon a diminished scale. Thus the weight W may be so adapted that the weight W′, which if it fell freely would descend through 193 inches in one second, shall only descend one inch in a second, so that the spaces through which the preponderating weight would descend would in that case be 193 times less than those through which a body falling freely would descend.

There are various accessories connected with Atwood's machine, such as a pendulum to mark the time of the fall, and other arrangements to determine the velocity acquired at the end of successive seconds, which need not be detailed here.

79. If a body, instead of being let fall freely under the sole action of gravity, be projected in any given direction with a certain force, it will, instead of descending in a vertical line, move in a curve called a *parabola.*

Let W (*fig.* 14.) be the place of the body at the moment it receives the impulse; let W be the vertical line in which it would fall, and let it be supposed to be projected by any force, as a bullet is from a gun, in the horizontal direction W M, with such a velocity that if it were not affected by gravity it would move through the space W I′ in the first second, from I′ to II′ in the next second, from II′ to III′ in the following second, and so on. Then sup-

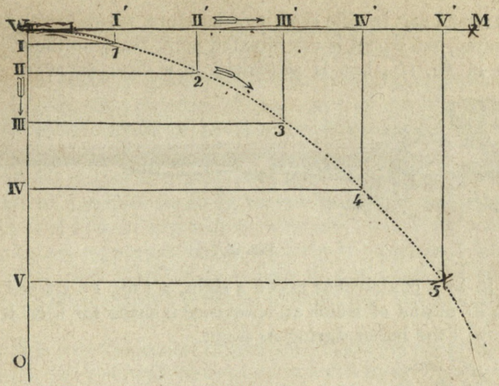


Fig. 14.

pose that if it were falling freely it would in the first second arrive at I, at the end of the next second at II, at the end of the following second at III, and so on. In the case of a body when affected at once, as it will necessarily be, by the force of projection and the force of gravity, it will by the principle of the composition of motion already explained, be found at 1 at the end of the first second, at 2 at the end of the next second, at 3 at the end of the following second, and so on; so that the body will describe the dotted curved line shown in the figure, this curved line being that which is called a *parabola*.

80. If instead of being projected horizontally the body be projected obliquely, the circumstances attending its motion and the course it will describe will be illustrated in the same manner by *fig.* 15.

81. It follows from this, that if a ball be propelled from a gun in the horizontal direction, it will necessarily drop below the level of the line of aim to a greater or less extent before it strikes the

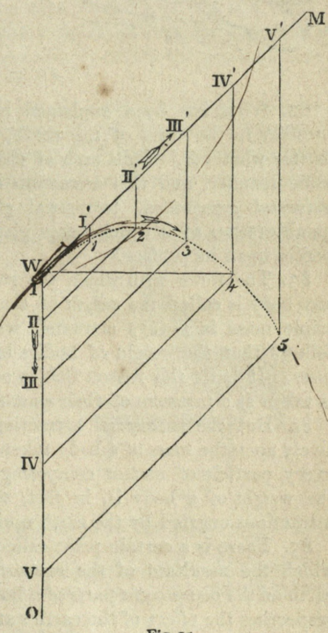


Fig. 15.

object aimed at. In rifle shooting, therefore, where great precision is required, the barrel is not directed point blank to the object, as shown in *fig.* 16., but is presented in a direction more or less

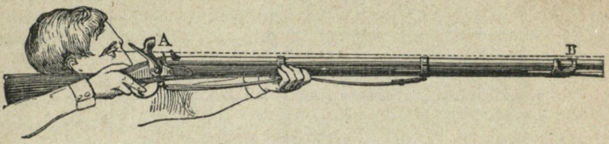


Fig. 16.

above it, by a contrivance called a sight, A (*fig.* 17.), fixed on the barrel, by means of which an allowance is made for what is called the drop of the bullet during its flight.

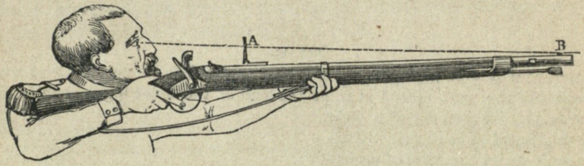


Fig. 17.

82. What has been explained in the preceding pages is not peculiar to the mass of the earth, but common to all masses of matter whatever. Thus each of the planets attracts bodies in the same manner, and this attraction in the general sense is called *universal gravitation*, terrestrial gravity being that particular manifestation of it which takes place between the earth and the bodies upon its surface.

83. The force with which the earth thus attracts the mass of any body is called the *weight* of that body, and since a double or triple mass is always attracted with double or triple force, it follows that the weight of bodies is always proportional to their mass. It is for this reason that in commerce the weight of bodies is taken as a measure of their quantity.

84. But the terrestrial attraction does not merely act collectively upon the mass of a body taken as a whole, but separately on every particle of matter composing the body, and consequently the weight of a body is, in fact, the aggregate of the separate attractions exerted by the earth upon all its component particles.

85. There is a certain point called the *centre of gravity*, through which the resultant of the separate attractions exerted by the earth on the component parts of a body passes, so that all questions respecting the effect of the earth's attraction on bodies are greatly

simplified by considering this attraction to act only on the centre of gravity. It must, however, be remembered, that this way of viewing the action of gravity is, strictly speaking, applicable only to solid bodies, the properties of the centre of gravity in the case of fluids being subject to peculiar conditions which will be explained hereafter.

86. If the centre of gravity of a solid body be supported, the attraction of the earth on all its parts will balance each other, and the body will rest in any position whatever; but if the centre of gravity be not supported, and if the body be suspended from any other point, then it will only remain at rest when the centre of gravity is either directly *under* or directly *over* the point of support.

If in this case the centre of gravity be directly *under* the point of support, the body will rest steady, and will return to its position if disturbed from it. This is called accordingly the position of *stable equilibrium.*

But if the centre of gravity be directly *over* the point of support, then upon the least disturbance that centre will descend until it comes directly *under* the point of support, so that the body will in fact be overturned. This is accordingly called the position of *unstable equilibrium.*

87. A vertical line drawn from the centre of gravity is called its *line of direction*, and the position of this line has an important relation to the stability of the body. If it fall within the base, the body will be supported; but if it fall outside the base, the body will be overturned.

In *fig.* 18. the line of direction from G falls within the base, and in *fig.* 19.

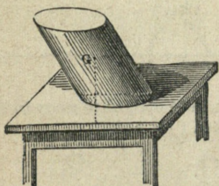


Fig. 18.

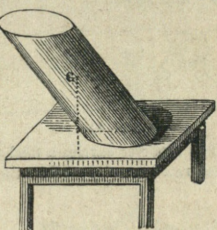


Fig. 19.

it falls outside the base. The body will stand on the table in *fig.* 18., but will fall in *fig.* 19.

88. When a load is placed at a considerable height above the wheels of a waggon, the centre of gravity is elevated, and the carriage becomes proportionately unstable.

In coaches for the conveyance of passengers, the luggage is therefore very unsafely placed on the roof.

Drays for carrying heavy loads are often constructed so that the chief weight is placed below the axle of the wheels. If a large table be placed on a single leg in its centre it will be impracticable to make it stand firm, but if the foot on which it rests terminate in a tripod, it will have the same stability as if it had three legs attached to the parts directly over the points where the feet rest. (*Fig.* 20.)

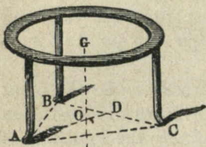


Fig. 20.

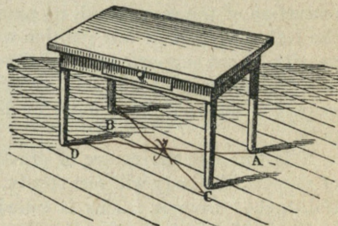


Fig. 21.

If there be four or more legs the table may be unstable, even though the centre of gravity fall within the base, and will be so if the ends of the legs A, B, C, D be not in the same plane.

When a man stands, the line of direction of his weight must fall within the base formed by his feet (*fig.* 22.). When he walks, the legs being alternately elevated from the ground, the centre of gravity is either unsupported or thrown from one side to another, the body being also thrown a little forward, to give the centre of gravity a tendency to fall in the direction of the toes. The flexibility of the knee-joint is useful in humouring the centre of gravity, as illustrated in *figs.* 23. and 24.

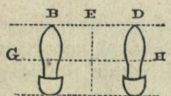


Fig. 22.

Fig. 23.

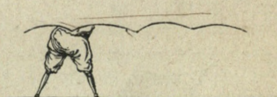


Fig. 24.

When a porter carries a load upon his back, he is obliged to stoop to bring the centre of gravity within the base of his feet, (*fig.* 25.)

Fig. 25.

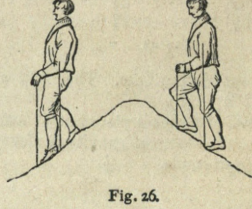


Fig. 26.

In ascending or descending a hill, the body of the pedestrian being vertical, while the hill is inclined, the position assumed is shown in *fig.* 26.

A person sitting in a chair cannot rise from it without stooping forward to bring the centre of gravity over the feet.

89. Unstable equilibrium in general is characterised by the centre of gravity having the highest position it is capable of as-

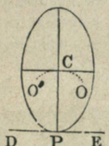


Fig. 27.

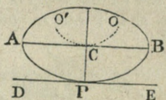


Fig. 28.

suming (*fig.* 27.); and stable equilibrium, on the contrary, when it is in the lowest position it is capable of assuming (*fig.* 28.).

90. When a body is so placed, that if it move the centre of gravity moves in a horizontal line, neither rising nor falling, it is said to be in *neutral equilibrium*.

An example of neutral equilibrium is presented in *fig.* 29.

Children's toys are constructed to show the play of the centre of gravity. Thus, at *fig.* 30., a body made of some light substance, such as cork, has a

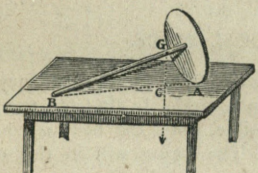


Fig. 29.

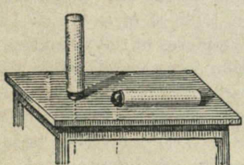


Fig. 30.

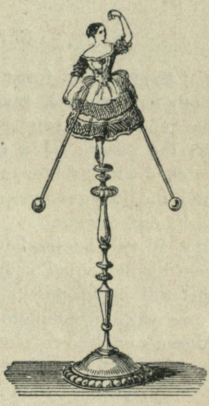


Fig. 31.

piece of lead attached to one of its extremities. If it be placed on the light end, which is rounded, it will by an apparently spontaneous motion invert its position, and a sort of tumbler will be formed. In *fig.* 31. a toy is represented which will be easily understood from what has been explained.

91. When a public exhibitor balances a sword by supporting its point in unstable equilibrium, the dexterity is shown by humouring his finger so as to keep the point under the centre of gravity.

A metal plate is sometimes made to spin on the point of a rod supported on the finger. The spinning motion in this case, instead of rendering the feat difficult, greatly facilitates it, since the centre of gravity revolving constantly round the point of support has a tendency at one minute to make the body fall on one side, which is instantly changed by a contrary tendency when it comes to the opposite side. It is in this way that the common effect of the spinning top is explained, *fig.* 32. The top continues so long as it spins as if it were in stable equilibrium, as in *fig.* 33.

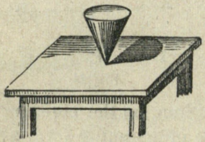


Fig. 32.

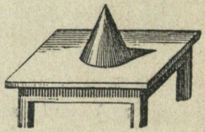


Fig. 33.

CHAP. V.

CENTRIFUGAL FORCE.

92. Centrifugal force is the name given to the tendency which a body has, when it revolves in a circle, to fly from the centre. This tendency is rendered sensible, when the body is connected with the centre by a string. The string will in this case be stretched with greater or less force, according to the velocity with which the body revolves, the radius of the circle in which it moves, and its own weight.

93. If two bodies having equal weight are whirled round a circle having equal radii, the centrifugal force which they will exert will be proportional to the squares of the velocities. Thus if one make a complete revolution in a second, while the other makes a complete revolution in half a second, the latter will stretch the string with four times as much force as the former. This may be easily verified by actual experiment, if the string be attached to any instrument by which its tension can be measured.

94. If two bodies be whirled round by strings of unequal length, and revolving in the same time, the centrifugal force will be in the exact proportion of the lengths of the strings; the longer the string the greater will be the force with which it is stretched.

95. Other things being the same, the centrifugal force will always be in the proportion of the weight of the body which is whirled round.

96. Various forms of apparatus are contrived for illustrating experimentally the laws of centrifugal force. One of these is shown in *fig*. 34., where the revolving body E reacts against a spring.

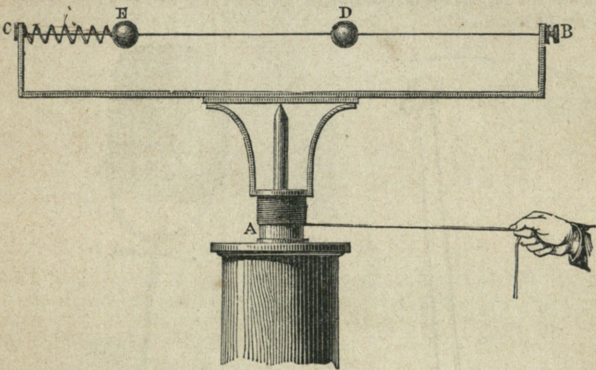


Fig. 34.

97. Numerous familiar examples illustrate centrifugal force.

A horseman or pedestrian passing round a corner moves in a curve, and consequently is affected by centrifugal force directed from the centre of the

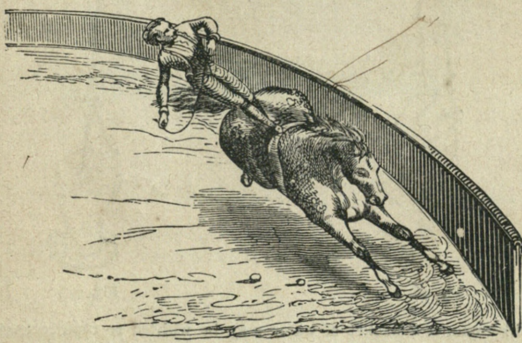


Fig. 35.

curve, which increases his velocity, and impresses on his body a force directed from the corner. He resists this by inclining his body towards the corner. An animal made to move in a ring, as is customary in training horses, always inclines towards the centre of the ring.

In equestrian feats not only the horse, but the rider inclines towards the centre (*fig.* 35.), and according as the rapidity increases, the inclination becomes more considerable. If a stone or weight be placed in a sling which is whirled round by the hand in a direction perpendicular to the ground, the stone will not fall out of the sling, even when it is at the top of its circuit. (*fig.* 36.)

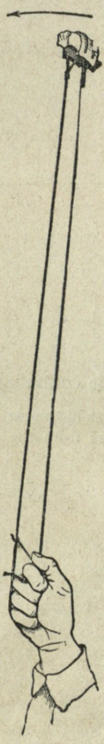


Fig. 36.

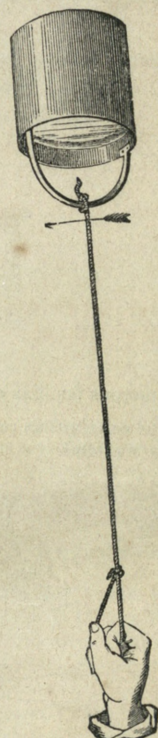


Fig. 37

In like manner a bucket of water may be whirled so rapidly that, even when the mouth is presented downwards, the water will be retained in it, *fig.* 37.

Water may be made to ascend in tubes, or to rise up the sides of a vessel the middle becoming concave, by the whirling apparatus, shown in *figs.* 38. and 39.

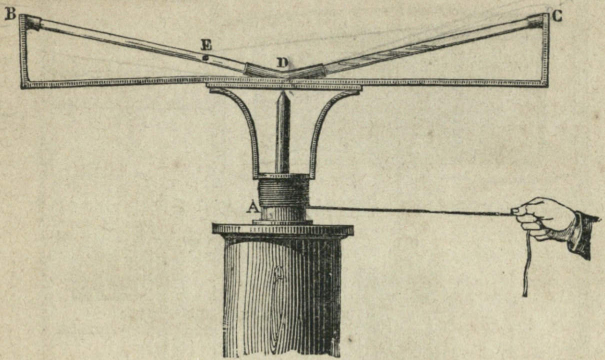


Fig. 38.

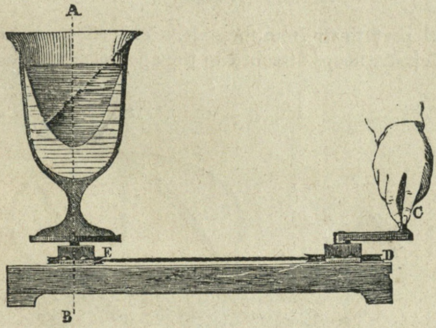


Fig. 39.

A drying machine for laundries, working by the agency of centrifugal force, is shown in *fig.* 40.

The wet linen is pressed against the sides by the centrifugal force, and the water squeezed from it is discharged by an apparatus provided for the purpose.

98. The globe of the earth turning upon its axis once in twenty-four hours is affected by centrifugal force, and since when it commenced its motion of rotation, it was in a fluid state, it assumed the form of a flattened spheroid, owing to the tendency of the

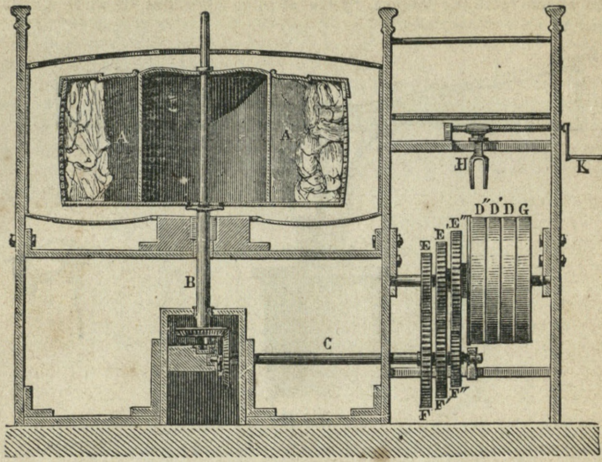


Fig. 40.

equatorial part to fly from the axis. This effect is illustrated by means of elastic hoops attached to the apparatus shown in *fig*. 41.

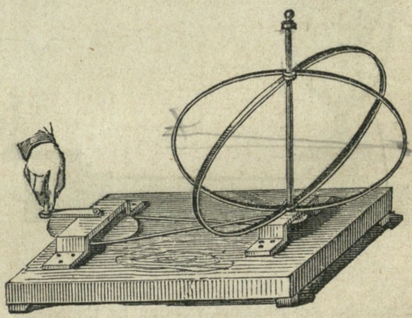


Fig. 41.

CHAP. VI.

MOLECULAR FORCE.

99. Besides the force which masses of matter exercise upon one another, there is another class which is manifested between their molecules, and which act only at imperceptible distances. These are called molecular forces.

100. One of these, which is attended with the most obvious effects, is called *cohesion*. In solid bodies, the component particles are held together by a force which resists their separation with greater or less energy, so that to break them, or pulverise them, or, in short, to separate their parts in any way, requires the application of a force more or less considerable, according to the nature of the body. It is on this force of cohesion that depends the hardness and tenacity of a body. All solids must necessarily possess it to a greater or lesser degree, since otherwise they would fall to pieces by their own weight.

101. A liquid consists of parts which do not cohere with sufficient force to prevent their separation by their mere weight. Thus a mass of liquid placed upon a plane will separate by reason of the weight of its particles, and will spread itself in a film, more or less thin, over the surface. Nevertheless, even liquids exhibit some slight degree of cohesion, which is manifested by their tendency to form into spherical drops; a sphere being the greatest volume which can be contained within a given surface. Thus particles of water falling in the atmosphere attract each other, and collect in spherules forming rain. If such spherules after their formation be exposed to cold, they harden and form hailstones. If a little mercury be let fall on a sheet of paper, it will collect in small silvery globules, notwithstanding the tendency of the gravity of its particles to make it spread over the paper in fine dust. Innumerable examples present themselves of this class of phenomena. The tear as it falls from the eye collects in a spherule upon the cheek; the dew forms a translucent globule on the leaves of plants.

102. The manufacture of shot presents one of the most striking examples of this phenomenon in the arts. The lead, in a state of fusion, is poured into a sieve, the meshes of which determine the magnitude of the shot, at the height of about 200 feet from the ground. The shower of liquid metal, after passing through the sieve, forms, like rain in the atmosphere, spherules which, before they reach the ground, are cooled and solidified.

These spherules form the common shot used in sporting, and the precision of their spherical form shows how regularly the liquid obeys the geometrical law, that a sphere contains the greatest volume within a given surface.

103. Aeriform bodies or gases are characterised, not merely by the absence of all cohesion between their particles, but by the presence of a contrary force of mutual repulsion. Air included in a cylinder under an air-tight piston will expand so as to fill the increased volume as the piston is drawn up, and to this expansion there is no practical limit. This is explained by supposing that around each molecule of the air or gas there is a sphere of repulsion, so that each particle repels those around it. When the piston is raised to twice its former height, the air beneath it will expand into double its former volume.

In this case it must be concluded that the vacant spaces between the particles of air are twice as great as they were before the piston was raised. If the piston be again raised to double its present height, the same effect will take place. The air will again expand in virtue of the repulsive force prevailing among its particles, and the interstitial spaces separating the particles will be proportionally augmented.

There is no known limit to this expansive quality, and it consequently follows that the region through which the repulsive forces of gases act has a corresponding extent.

104. When the surfaces of bodies are rendered smooth, or brought into close contact by pressure, they will adhere together with considerable force. The force manifested in this case is called adhesion.

Innumerable examples of the adhesion of solid bodies are familiar to daily experience. We may write with chalk, or with a pencil, or charcoal on a wall or on a ceiling, although the effect of gravity would be to cause the particles abraded from the chalk, the lead, or the charcoal to fall from the wall or the ceiling. Dust floating in the air sticks to the wall or ceiling, in spite of the tendency of its gravity to fall from them.

105. The force of adhesion of solid surfaces one to another may be ascertained by placing the adhering surfaces in a horizontal position, the lower one being attached to a fixed point, and the upper one connected with the arm of a balance. The weight necessary to separate them is the measure of the adhesion. If we desire to ascertain the amount of adhesion per square inch of surface, it is only necessary to divide such weight by the magnitude of the adhering surface expressed in square inches.

It is on the adhesion between metallic surfaces when pressed strongly together that the efficacy of a locomotive engine depends. The driving-wheels press with a great weight upon the rails, and are made to revolve round their own centres by the force of the engine. If there were no adhesion, or even insufficient adhesion, between the tire of the wheel and the rail on which it is pressed, the wheel would turn without advancing; and this actually does happen in cases where the rails are greasy, and very frequently when they are covered with a hoar frost, the contact being then interrupted, and the matter between the wheel and the rail not offering the necessary adhesion.

106. The effect known amongst workers in metal as the *bite* is the adhesion of two metallic surfaces brought into extremely close contact. It may be doubted whether this adhesion would not be diminished if some fluid were introduced between the surfaces.

107. The adhesion of the surface of solids may be rendered more intense than even the cohesion of the particles of the solids themselves by interposing between them some substance in a liquefied form, which hardens by cold, and which when hard has a strength equal to or greater than that of the solids which it unites. Glues, cements, and solders supply remarkable examples of this. Two pieces of wood glued together will break anywhere rather than at their joint. The processes of gilding and plating also supply examples of the adhesion of metals to each other.

108. The process of silvering mirrors is an example of the adhesion of metal to glass; and that of mortar in building is an example of the adhesion of earthy matters to each other.

Two pieces of caoutchouc, if pressed together upon freshly cut surfaces, will be found to unite as completely as if they composed one independent piece.

CHAP. VII.

ELEMENTS OF MACHINERY.

109. A *machine* is an instrument or apparatus consisting usually of various parts, mechanically connected one with another, the purpose of which is to modify a moving force, so as to adapt it to the performance of some special sort of work.

Thus, for example, a horse moving on a horizontal road is made to raise a weight vertically in the shaft of a mine, and men pulling at a rope in some direction more or less oblique are enabled to raise masses of heavy matter from the hold of a ship and transfer them to an adjacent wharf. In like manner, the force of steam acting on the piston of a steam-engine, so as to drive it alternately from end to end of the cylinder, may be made to keep a wheel in constant rotation, and to transmit the necessary force to all the machines of a great factory.

110. The force which gives motion to a machine is usually called the *power*, and the resistance which the machine is applied to overcome, whatever be its nature, is generally called the *weight*.

111. When the power and weight are adapted to each other, so that the one is capable of supporting the other without moving it, they are said to be in equilibrium. If the power be greater than this limit it will raise the weight, and if less, the weight will raise it.

112. Machines are either *simple* or *compound*. *Simple machines* are those which consist of a single moving piece; *complex*, those

which consist of several moving pieces acting one upon the other.

113. A *lever* is a simple machine which turns upon a fixed point of support or axis, called an *axis*, *fulcrum*, or *prop*.

114. The distance of the direction of the power from the fulcrum is called the *leverage of the power*, and the distance of the direction of the weight from the fulcrum is called the *leverage of the weight*. The greater the leverage of the power is, and the less the leverage of the weight, the greater will be the efficacy of the machine.

115. The mechanical effect of the power is estimated by multiplying the power by its leverage, and the mechanical resistance of the weight is found by multiplying the weight by its leverage. The power and weight will be in equilibrium when the *product found by multiplying the power by its leverage, is equal to the product found by multiplying the weight by its leverage*. If the former product be greater than the latter, the power will prevail over the weight and raise it. If it be less, the power will be insufficient even to support the weight.

116. Levers are of three kinds. In the *first kind* the fulcrum is between the power and weight (*fig.* 42.); in the *second kind*

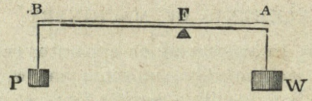


Fig. 42.

(*fig.* 43.) the weight is between the power and the fulcrum; and in the *third* (*fig.* 44.), the power is between the weight and the fulcrum.

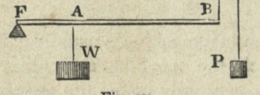


Fig. 43.

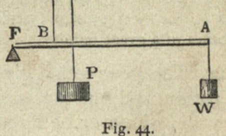


Fig. 44.

117. When a lever has equal arms, the leverage of the weight will equal the leverage of the power, and in that case the power and weight will be in equilibrium when they are equal. This is the case with the common *balance* (*fig.* 45.), where the substance weighed may be considered as the weight, and the weights which balance it as the power.

118. Various other weighing instruments are used, which consist of levers with unequal arms, and consequently in these the power and weight when in equilibrium are not equal. In general a great leverage is given to the power or balancing weight, and a small leverage to the thing weighed, so that small weights are sufficient to weigh very ponderous substances.

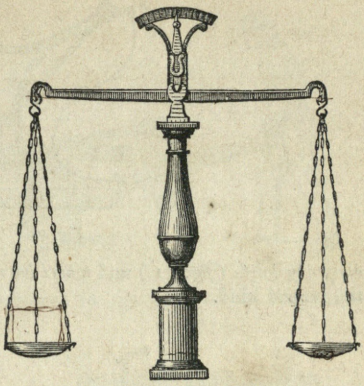


Fig. 45.

119. The *steelyard* (*fig.* 46.) is a lever with unequal arms. In this case the leverage of the balancing weight can be increased or diminished at pleasure, so that such a position can be given to it as can balance the substance weighed. The weight of the latter is determined in this case by the leverage and the balancing weight combined.

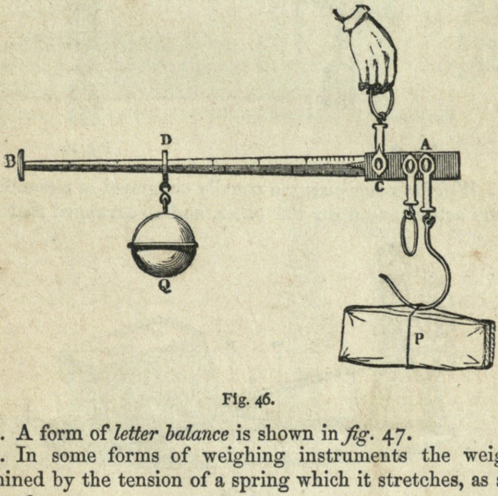


Fig. 46.

120. A form of *letter balance* is shown in *fig.* 47.

121. In some forms of weighing instruments the weight is determined by the tension of a spring which it stretches, as shown in *figs.* 48, 49.

122. A *crow bar* (*fig.* 50.) is a lever of the first kind, and a

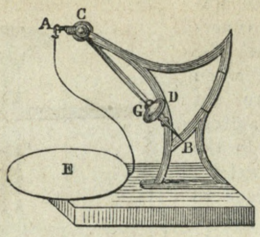


Fig. 47.

chopping knife (*fig.* 51.) and *wheel barrow* (*fig.* 52.) are levers of the second kind.

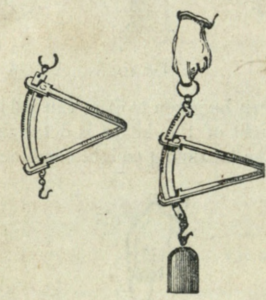


Fig. 48.

Fig. 49.

123. *Weighing machines* are usually composed of a combination of levers acting one upon the other, and so arranged that all the

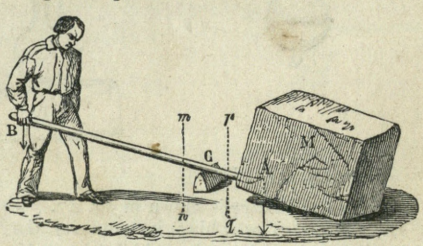


Fig. 50.

leverages directed on the side of the power are great, while those directed on the side of the weight are small. One form of weighing

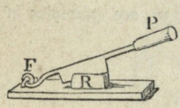


Fig. 51.

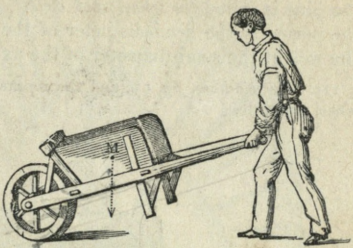


Fig. 52.

machine is shown in perspective in *fig.* 53., and in section in *fig.* 54.

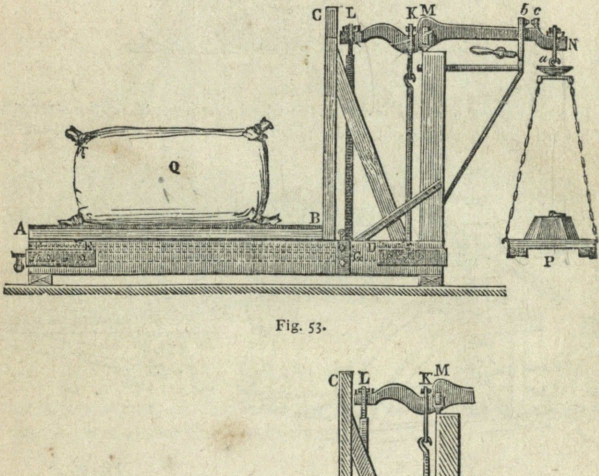


Fig. 53.

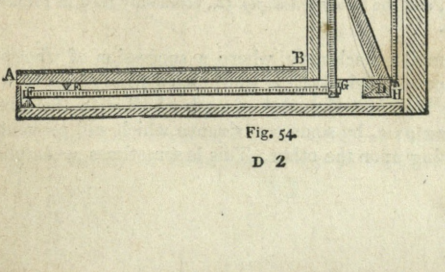


Fig. 54.

124. When the lever, instead of having the form of a rod or arm, has the form of a wheel of which its fulcrum is the axle, the machine is called *the wheel and axle*. In this case the leverage of the power is the semi-diameter of the wheel, and the leverage of the weight the semi-diameter of the axle.

125. The *windlass, fig.* 55., and the *capstan, fig.* 56., are examples of the wheel and axle.

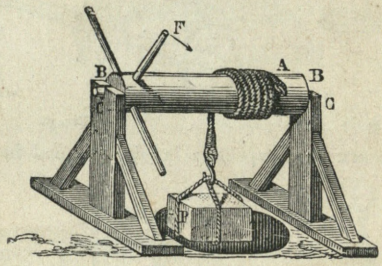


Fig. 55.

In some cases the man who works the wheel operates not by the strength of his arm, but by the weight of his body. In that case some provision is

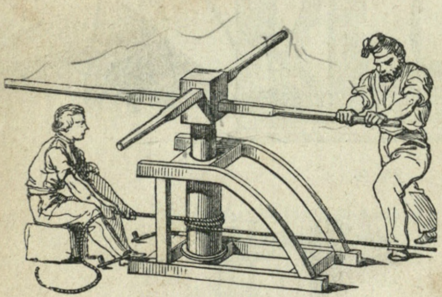


Fig. 56.

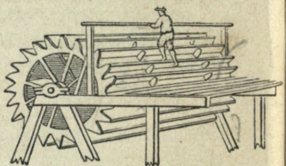


Fig. 57.

made by which he can mount upon the circumference of the wheel. The *treadmill, fig.* 57., and the *ladder-wheel, fig.* 58., commonly used in France, are examples of this.

126. In complex machinery, where a succession of wheels act one upon the other, their force is transmitted from wheel to wheel by connecting together the edge of each wheel with the edge of each succeeding axle, by some contrivance which will prevent the one from slipping upon the other. This is sometimes accomplished

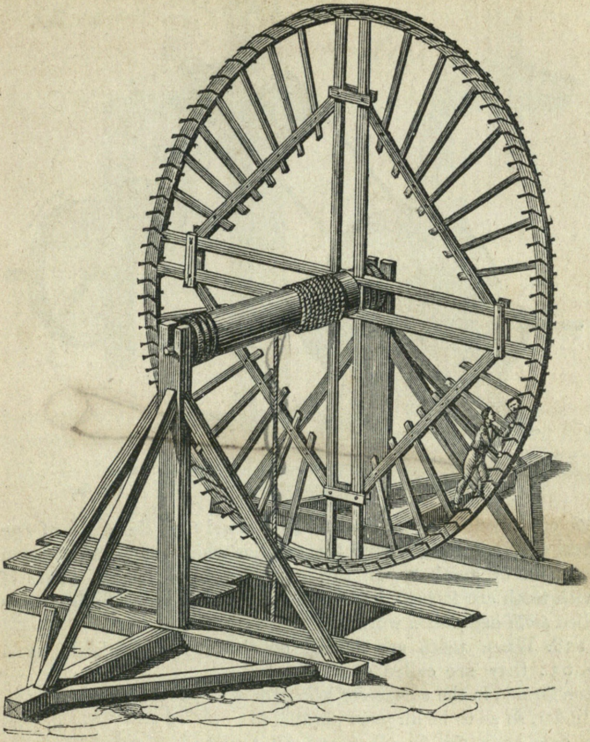


Fig. 58.

by *endless bands*, as shown in *figs*. 59, 60, 61., and sometimes by the rough edges of the wheels themselves, as in *fig*. 62.

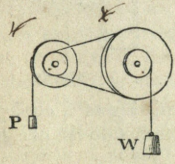


Fig. 59.

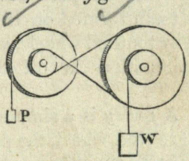


Fig. 60.

127. The most usual and most effectual manner, however, of transmitting the action of wheels one to another, is by means of

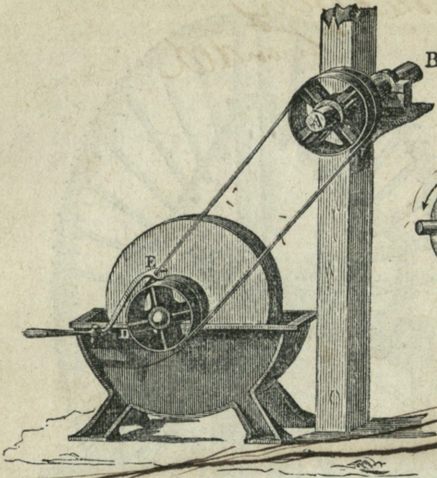


Fig. 61.

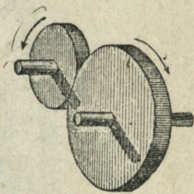


Fig. 62.

teeth cut upon their edges, and so formed that the teeth of one wheel shall be engaged with the cavities which intervene between the teeth of another. In this case the axles, on the edges of which teeth are formed, are called *pinions*, and the combination is called *tooth and pinion* work.

128. When teeth are formed on the edges of wheels, as in *fig*. 63., they are called spur wheels; when formed in the surface of a hoop or cylinder, so as to be directed parallel to the axis, as in *fig*. 64., they are called *crown wheels;* and when they are oblique to the axis, as in *fig*. 65., they are called *bevel wheels*. When a straight bar has teeth formed on it so as to be worked by toothed wheels, as in *fig*. 66., the combination is called *rack and pinion*.

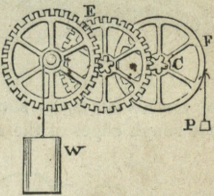


Fig. 63.

129. A *pulley* is a simple machine consisting of a cord passing over a grooved wheel, the power being attached to the one end and the weight to the other.

Pulleys are either fixed, as in *fig*. 67., or movable, as in *fig*. 68.

130. The principle upon which the mechanical effect of pulleys

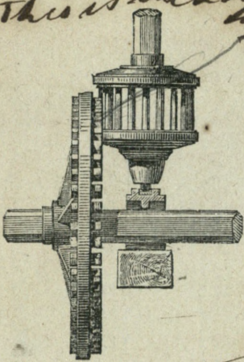


Fig. 64.

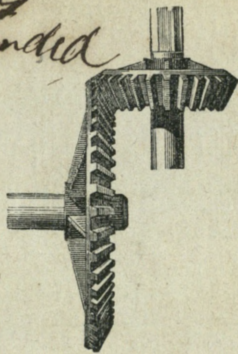


Fig. 65.

is determined, is that the same cord must suffer the same tension through its entire length; and from this it follows, that in the

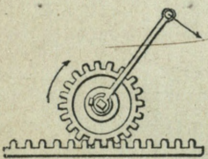


Fig. 66.

Fig. 67.

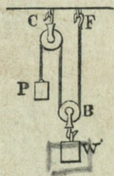


Fig. 68.

fixed pulley (*fig.* 67.) the power and weight are equal, and in a movable pulley, such as that shown in *fig.* 68., the weight is twice the power, since the weight is supported by the tension of two parts of the same cord B F and C B, while the power is supported by only one, P C.

131. By passing the same cord successively round a series of grooved wheels fixed in the same block, pulleys may be formed which will support a weight as many times greater than the power as there are parts of the string combined to support the block to which the weight is attached. Different forms of pulleys of this kind are shown in *figs.* 69, 70.

132. An *inclined plane* is a simple machine consisting, as its name implies, of a hard plane surface inclined to the horizontal line upon which the weight rests, as shown in *fig.* 71.

The power in this case is less than the weight in proportion to

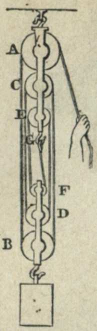


Fig. 69.

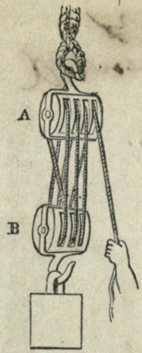


Fig. 70.

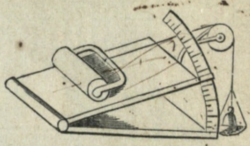


Fig. 71.

the height of the plane to its length. Practical examples of the inclined plane are shown in *figs.* 72, 73.

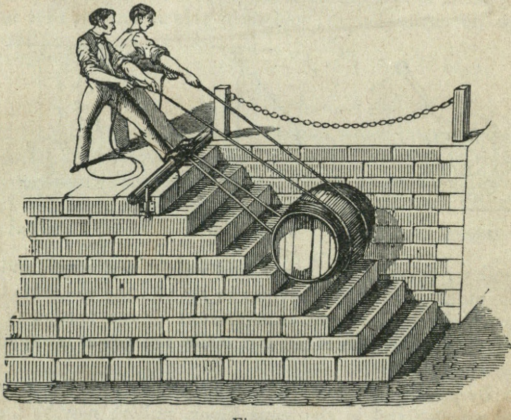


Fig. 72.

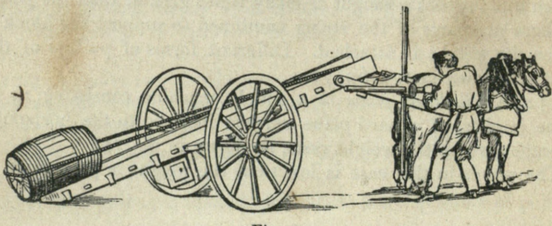


Fig. 73.

133. The *wedge* is a simple machine consisting of two inclined planes placed at an oblique angle forced between bodies, or the parts of a body, intended to be separated, as shown in *fig.* 74.

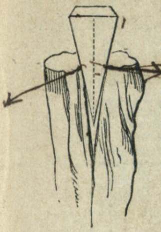


Fig. 74.

In theory the power of the wedge is to the weight or resistance as half the back of the wedge is to its length; but this theory is not applicable in practice with any degree of accuracy, owing to the enormous disproportion which the friction of these machines bears to the power.

134. The cases in which wedges are most generally used in the arts and manufactures, are those in which an intense force is required to be exerted through a very small space. This instrument is therefore used for splitting masses of timber or stone; for raising vessels in docks, when they are about to be launched, by being driven under their keels; in presses where the juice of seeds, fruits, or other substances are required to be extracted; as, for example, in the oil mill, in which the seeds from which the oil is extracted are introduced into hair bags, which being placed between planes of hard wood are pressed by wedges. The pressure exerted by the wedges is so intense that the dry seeds are converted into solid masses as hard and compact as the most dense woods. Wedges have been used occasionally to restore to the perpendicular, edifices which have inclined owing to the sinking of their foundations.

135. All cutting and piercing instruments, such as knives, razors, shears, scissors, chisels, nails, pins, needles, &c., are wedges. The angle of the wedge in all these cases is more or less acute, according to the purpose to which it is applied. Chisels intended to cut wood have their edge at an angle of about 30°; for cutting iron from 50° to 60°, and for brass about 80° to 90°. In general, tools which are urged by pressure admit of being sharper than those which are driven by percussion. The softer or more yielding the substance to be divided is, the more acute the wedge may be constructed.

In many cases the efficiency of the wedge depends on that which is entirely omitted in its theory, viz., the friction which arises between its surface and the substance which it divides. This is the case when pins, bolts, or nails are used for binding the parts of structures together, in which case, were it not for the friction, they would recoil from their places and fail to produce the desired effect. Even when the wedge is used as a mechanical engine the presence of friction is absolutely indispensable to its practical utility.

136. The *screw* is an inclined plane, which winds spirally round a cylinder. The interval between its successive spires is called the pitch of the screw (*fig.* 75.).

The power of the screw is to the resistance, as the distance between two contiguous threads is to the circumference described by the power, and as the power usually acts at the extremity of a lever inserted in the head of the screw (*fig.* 76.), it is found

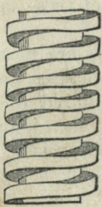


Fig. 75.

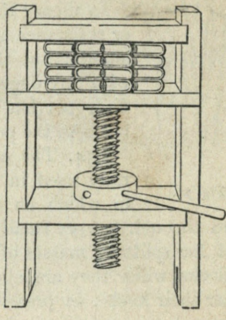


Fig. 76.

that the weight or resistance will in all cases be in an enormous proportion to the power.

137. In cases where liquids or juices are to be expressed from solid bodies, the screw is the agent generally employed. It is also used in coining, where the impression of a die is to be made upon a piece of metal, and in producing the impression of a seal upon wax or other substance adapted to receive it. When soft and light materials, such as cotton, are to be reduced to a convenient bulk for transportation, the screw is used to compress them, and they are thus reduced into hard dense masses. In printing, the paper is sometimes urged by a severe and sudden pressure upon the types by means of a screw.

138. A screw may be cut upon a cylinder by placing the cylinder in a turning-lathe, and giving it a rotatory motion upon its axis. The cutting point is then presented to the cylinder and moved in the direction of its length at such a rate as to be carried through the distance between the intended threads while the cylinder revolves once. The relative motions of the cutting point and the cylinder being preserved with perfect uniformity, the thread will be cut from one end to the other. The shape of the threads may be either square, as in *fig.* 75., or angular, as in *fig.* 76.

139. The slow motion which may be imparted to the end of a fine screw by a considerable motion of the power renders it an instrument peculiarly well adapted to the measurement of very minute motions and spaces, the magnitude of which could scarcely be ascertained by any other means.

To explain the manner in which it is applied: suppose a screw to be so

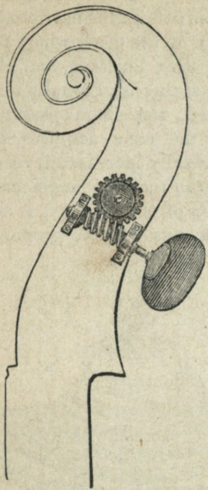


Fig. 77.

cut as to have fifty threads in an inch, each revolution of the screw will advance its point through the fiftieth part of an inch. Now, suppose the head of the screw to be a circle whose diameter is an inch, the circumference of the head will be something more than three inches: this may be easily divided into a hundred equal parts, distinctly visible. If a fixed index be presented to this graduated circumference, the hundredth part of a revolution of the screw may be observed by noting the passage of one division of the head under the index. Since one entire revolution of the head moves the point through the fiftieth of an inch, one division will correspond to the five-thousandth of an inch. In order to observe the motion of the point of the screw in this case, a fine wire is attached to it, which is carried across the field of view of a powerful microscope, by which the motion is so magnified as to be distinctly perceptible.

140. When the thread of a screw acts in the teeth of a wheel, the screw is called a *worm* or *endless screw* (*fig.* 77.).

141. A *regulator* consists of a mechanical contrivance the purpose of which is, as the name implies, to regulate the power, that is, to render it proportionate to the resistance. They generally, but not always, act upon that point of the machine which commands the supply of the power, by means of some mechanism adapted to check the moving principle whenever the motion becomes accelerated, and increase the supply when it becomes retarded.

In a water-wheel, for example, this is accomplished by acting upon the shuttle, and in windmills by the adjustment of the sails; in the steam-engine by acting on a valve, called the throttle valve, placed in the main pipe through which the steam flows from the boiler to the cylinder; and in clock and watch work by the escapement wheel, so as to prevent the acceleration of the motion which would arise from the uninterrupted action of the moving weight or main spring.

142. The *governor*, which is one form of regulator of the steam-engine, is shown in *fig.* 78.

When the velocity becomes too great, the balls B, B fly out from the axis, and partly close the throttle valve V, and when the motion becomes too slow, they collapse towards the axis and open the throttle valve.

143. In watch-work the varying power of the *main-spring* is equalised by the *fusee*, as shown in *fig.* 79.

The form of the fusee is conical, and when the tension of the

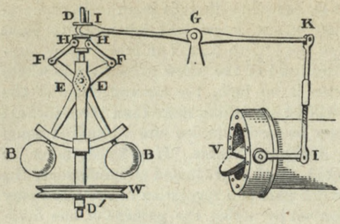


Fig. 78.

main-spring is greatest, the chain acts on the narrowest part of the cone, where it has least leverage, and as the spring is gradually relaxed, the chain passing off the cone acquires a gradually increased leverage, so that the augmentation of the leverage is as nearly as possible proportionate to the diminished energy of the spring.

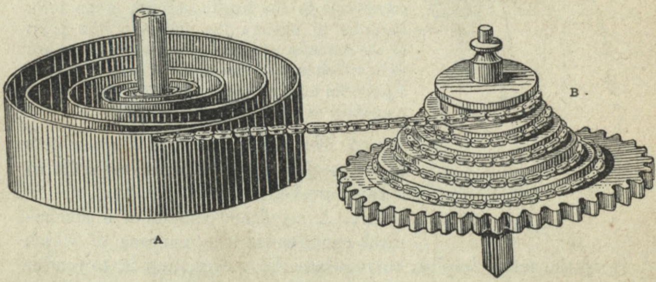


Fig. 79.

144. In the successive positions assumed by the parts of a machine in its motion, the effect of the power upon the working point varies, and cases occur in which its effect is even for a moment altogether interrupted, and in which the machinery loses all power over the resistance. The consequence of this would be, that, even though the power and resistance should both be uniform, the action of the former upon the latter would be subject to periodical variation.

145. To render this, as well as the mechanical provision made to remedy it, more clearly intelligible, we shall take the example of the common crank used in various machines. A crank is nothing more than a double winch. It is represented complete with both its arms in *fig.* 80. Attached to the middle of C D, by a joint, is a rod, which is the means of imparting the effect of the power to the crank. This rod is driven by an alternate motion like the brake of a pump. The bar C D is carried with a circular motion round the axis A F.

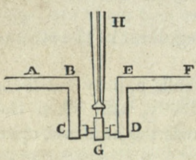


Fig. 80.

Let the machine viewed in the direction A B E F of the axis be conceived to be represented in *fig.* 81., where A represents the centre round which the motion is to be produced, and G the point where the connecting rod G H is attached to the arm of the crank. The circle through which G is to be urged by the rod is represented by the dotted line. In the position represented in *fig.* 81., the rod acting in the direction H G has its full power to turn the crank G A round the centre A. As the crank comes into the position represented in *fig.* 82., this power is diminished; and when the point G comes immediately below A, as in *fig.* 83., the force in the direction H G has no

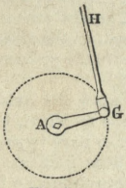


Fig. 81.

Fig. 82.

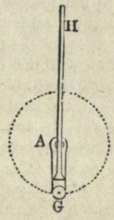


Fig. 83.

effect in turning the crank round A, but, on the contrary, is entirely expended in pulling the crank in the direction G A, and therefore only acts on the pivots or gudgeons which support the axle.

At this crisis of the motion, therefore, the whole effective energy of the power is annihilated.

After the crank has passed to the position represented in *fig.* 84., the direction of the force which acts upon the connecting rod is changed, and now the crank is drawn upward in the direction G H. In this position the moving force has some efficacy to produce rotation round A, which efficacy continually increases until the crank attains the position shown in *fig.* 85., when its power is greatest. Passing from this position, its efficacy is continually diminished until the point G comes immediately above the axis A (*fig.* 86.). Here again the power loses all its efficacy to turn the axle. The force in the direction G H or H G can obviously produce no other effect than a strain upon the pivots or gudgeons.

Fig. 84.

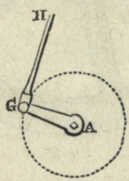


Fig. 85.

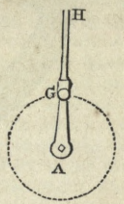


Fig. 86.

It will be evident from this that the action of the power transmitted to the working point G is very variable. At the dead points represented in *figs.* 83. and 86., the machine, if depending solely upon the moving power, must come to rest, for at both points the whole effect of the power would be exerted in producing pressure on the axle and gudgeons of the crank. Through a small space at either side of those dead points, the effect transmitted to G, though not absolutely nothing, is almost evanescent, so that it may be considered that through a small arc at either side of each of the dead points the machine is still inert.

It must, however, be considered that, in virtue of its inertia, the motion which the machinery had previously to its arrival at its dead points has a tendency to continue; and if the resistance of the load and the effects of friction be not too great, this disposition to preserve its state of motion will extricate the machinery from the mechanical dilemma in which it is involved in these cases by the particular disposition of its parts. Although, however, the motion will not therefore be actually suspended, on the arrival of the crank at the dead points, it will be greatly retarded; and, on the other hand, when the power acquires its greatest activity, as it does in the position represented in *figs.* 81. and 85., it will be unduly accelerated.

146. These irregularities are equalised by fixing upon the axis of the crank, or at any other convenient part of the machine, a fly wheel, which is a massive ring of metal, connected with a central box or nave by comparatively light spokes, and turning on an axis with but little friction. If any force be applied to it, with that force, making some slight deduction for friction, it will move and will continue to move until some obstacle retard it, which obstacle will receive from it as much force as the fly wheel loses.

The effect of such a wheel (*fig.* 87.), applied to the parts moved by the

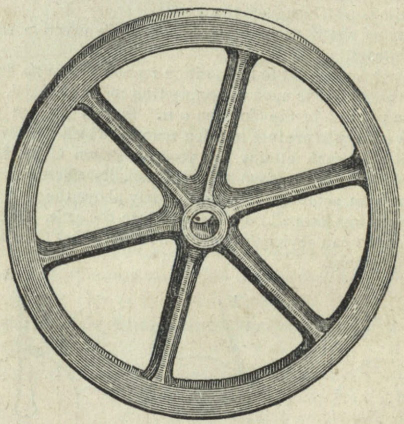


Fig. 87.

crank, will equalise the inequality which has just been described. When the crank assumes the position represented in *figs.* 81. and 85., where the power has full play upon it, the effect of the power is partly transmitted to the machine, and partly received by the movable rim of the fly wheel, to which it imparts increased momentum. There is here, it is true, an acceleration of the motion, but one which is comparatively small, inasmuch as the great mass of the fly wheel receives the momentum without sensible increase of speed. When the crank gets into the predicament represented at the dead points (*figs.* 83. and 86.), the momentum of the fly wheel, received when the crank acted with the most advantage, immediately conveys its force to the working-point G, extricates the machine, and carrying the crank out of the neighbourhood of the dead point, brings the power again to bear upon it.

147. The *pendulum*, which is the most perfect of regulators, is chiefly applied to clock-work. This instrument consists of a heavy disc of metal, which swings alternately from side to side with a vibrating motion. It is the property of such motion that all its vibrations shall be performed in precisely the same time.

The control of the pendulum is exercised upon the clock-work by means of a wheel E (*fig.* 88.), called the escapement wheel. The pendulum is connected with a piece ABC called from its form the anchor, the hooks of which catch alternately in the inclined teeth of the escapement wheel. The anchor swings right and left with the pendulum, and stops and liberates the teeth of the wheel E alternately, so that one tooth passes for each vibration. Were it not for this constant check acting upon the wheel E, its motion would be accelerated by the accelerated motion of the moving weight. The result of this combination is, that the motion of the wheel work is not, as is commonly supposed, continuous, but intermitting, being stopped each time that the hook *n* or *n'* of the anchor arrests a tooth of the escapement wheel E, and let on the moment it is disengaged. This intermitting motion is rendered visible by observing the seconds hand of a clock, which goes by starts, the starts corresponding to the oscillating of the anchor. A side view of the wheel work is presented in *fig.* 89., and a front view in *fig.* 90.

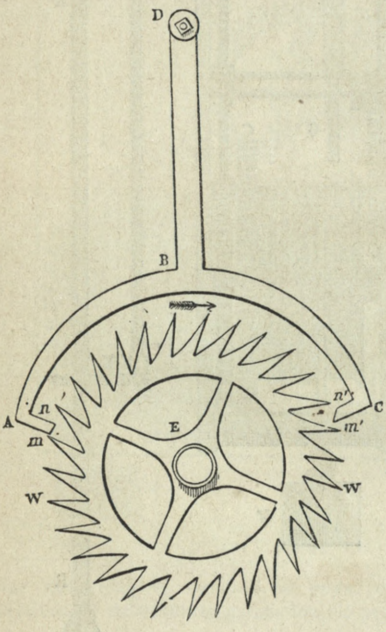


Fig. 88.

It will be evident upon inspection, that the moving power is the descending weight W, while the regulating power is the pendulum V.

148. In some cases a force is required much more intense than

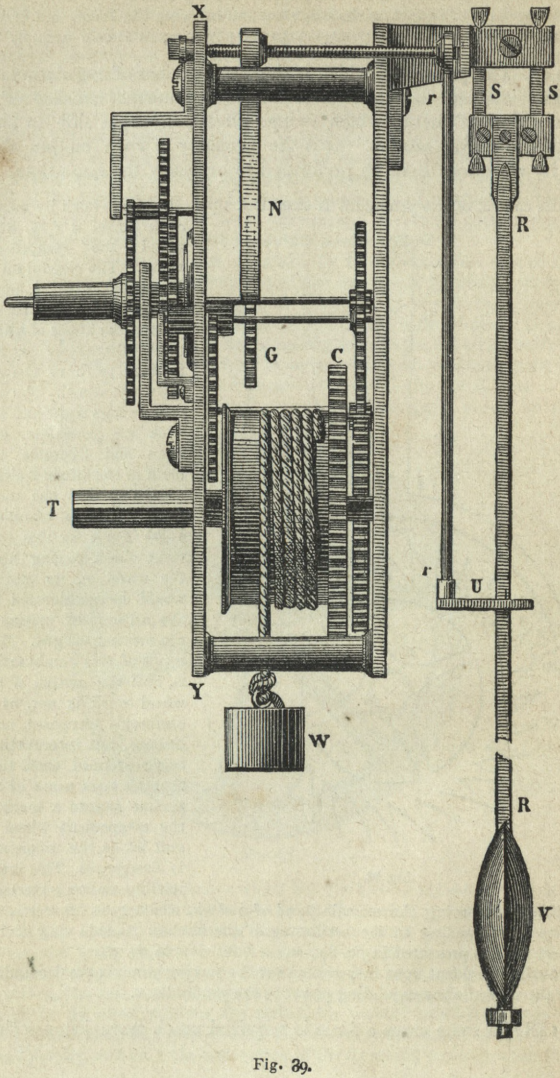


Fig. 39.

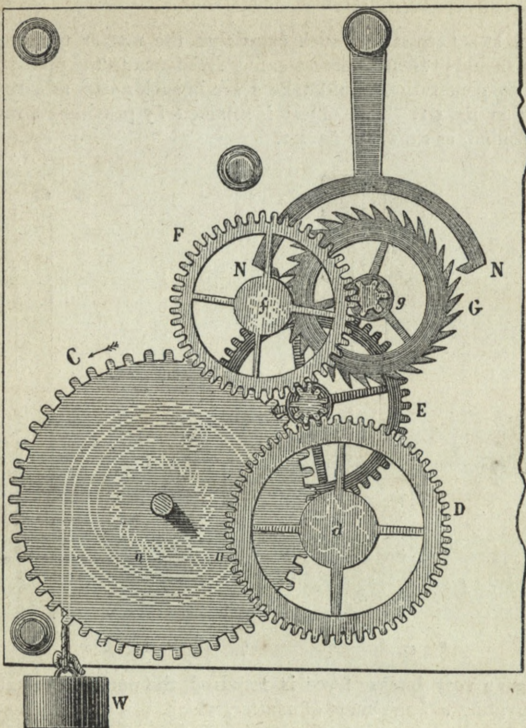


Fig. 90.

any which can be obtained by mere pressure. This object is attained by substituting percussion for pressure.

If, for example, it be required to cause a nail to penetrate a beam of wood, we should attempt in vain to accomplish this by producing any pressure, however great, on the head of the nail. A few blows of a hammer, nevertheless, easily effect this. In this case, the moving power is the hand, or other force which raises the hammer. The mass of the hammer, in falling on the head of the nail, imparts instantly to the nail the entire force which was exerted in lifting it, but with this difference, that such force, in raising the hammer, was developed in a certain definite time, whereas it is discharged upon the head of the nail in an instant.

The same observations apply to all cases in which percussion is used. In all these cases the force is developed in a definite time, but is discharged upon the resistance in an instant.

149. It is necessary in such cases that the matter to be penetrated should present a corresponding resistance to the percussion, since no penetration would take place in such a case as is represented in *fig.* 91. This object is attained by providing a resistance behind, as shown in *fig.* 92.

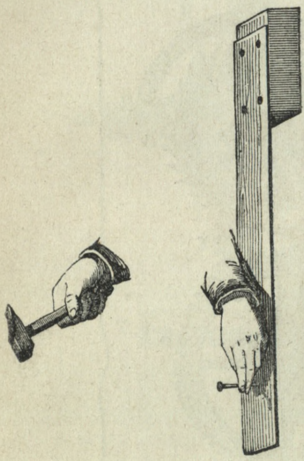


Fig. 91.

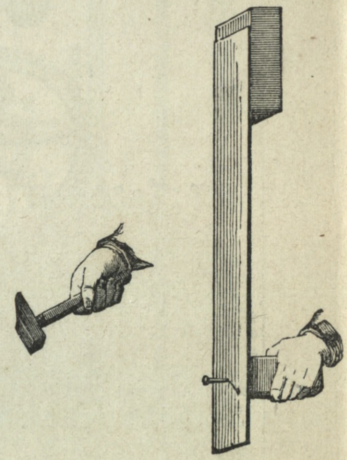


Fig. 92.

When a very intense force is required, the purpose is attained by providing a large mass of matter, which, being put in motion by the continued action of a force, discharges its accumulated energy in an instant upon the object to be affected by it.

150. A weapon called a *life-preserver* consists of a piece of lead sometimes attached to the end of a piece of cane or whalebone, with which a blow may be given with great force. Innumerable examples of the application of this principle will present themselves to every mind. Flails used in threshing, clubs, canes, whips, and all instruments used for striking, axes, hatchets, cleavers, and all instruments which act by a blow, present examples of this principle.

151. A *screw press* presents a familiar example of this. Heavy balls of metal A B, (*fig.* 93.) are fixed upon the ends of the screw lever, and whirled rapidly round. They transmit their whole momentum through the intervention of the screw, to the part upon which the instrument acts.

152. Mills for rolling metals or punching boiler plates supply striking examples of this accumulation of force. In these cases a large fly wheel is

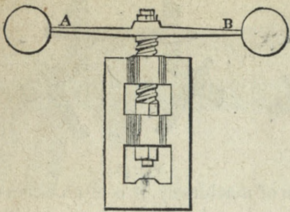


Fig. 93.

used, on which no load is placed, which is put in rapid revolution by the moving power, whatever it may be. When a sufficient momentum has been imparted to the wheel, the metal to be rolled or pierced is submitted to the machine, and is immediately flattened or perforated by it, depriving at the same time the fly wheel of a corresponding quantity of momentum.

153. In the same manner, a force may be obtained by the arms of men acting on a fly for a few seconds, sufficient to impress an image on a piece of metal by an instantaneous stroke. The fly is therefore the principal agent in coining-presses.

Some presses used in coining have flies with arms four feet long, bearing a hundredweight at each of their extremities. If such a velocity be imparted to such an arm that it shall make one revolution per second, the die will be driven against the metal with the same force as that with which $3\frac{3}{4}$ tons would fall from the height of 16 feet, which is an enormous power if the simplicity and compactness of the machine be considered.

154. The open work of fenders, fire grates, and similar ornamental articles constructed in metal, is produced by the action of a fly in the manner already described.

The cutting tool, shaped according to the pattern to be executed, is attached to the end of the screw, and the metal being held in a proper position beneath it, the fly is made to urge the tool downwards with such force as to stamp out pieces of the required figure. When the pattern is complicated, and it is necessary to preserve with exactness the relative situation of its different parts, a number of punches are impelled together, so as to strike the entire piece of metal at the same instant, and in this manner the most elaborate open work is executed by a single stroke of the hand.

155. Besides the simple machines commonly called mechanical powers which have been already enumerated, a great number of other expedients have been contrived for the modification of motion or force, a few of the most important of which will now be described.

156. Rotatory motion round an axis can be made to produce rotatory motion round other axes in other directions by various combinations of bevelled wheels, as is shown in *figs.* 94, 95, 96.

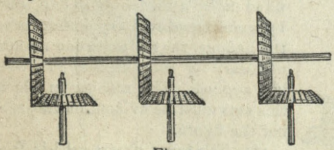


Fig. 94.

157. A most convenient contrivance, called from its inventor Hook's or the universal joint, is shown in *fig.* 97. and in a modified form in *fig.* 98.

This is frequently used in adjusting the position of large telescopes.

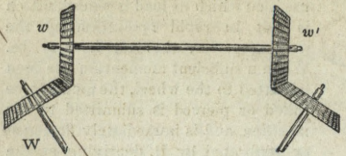


Fig. 95.

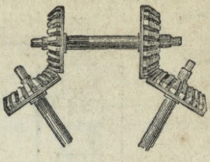


Fig. 96.

158. In the practical application of machinery, it is often necessary to connect a part having a continued circular motion with another which has a reciprocating or alternate motion, so that

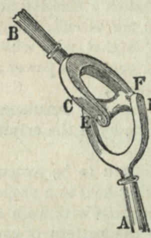


Fig. 97.

Fig. 98.

either may move the other. There are many contrivances by which this may be effected.

One of the most remarkable examples of it is presented in the escapements of watches and clocks.

159. A beam vibrating on an axis, and driven by the piston of a steam-engine, or any other power, may communicate rotatory motion to an axis by a connector and a crank.

A wheel A (*fig.* 99.) armed with wipers, acting upon a sledge-hammer B, fixed upon a centre or axle C, will, by a continued rotatory motion, give the hammer the reciprocating motion necessary for the purposes to which it is applied. The manner in which this acts must be evident on inspecting the figure.

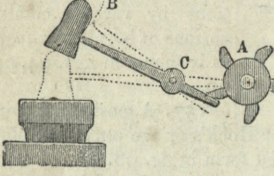


Fig. 99.

160. The large shears used in factories for cutting plates of metal are worked upon a similar principle. The lower edge of the shears (*fig.* 100.) is fixed, and the upper movable upon a joint. Under the extremity of the movable arm is placed a wheel, the contour of which has the form

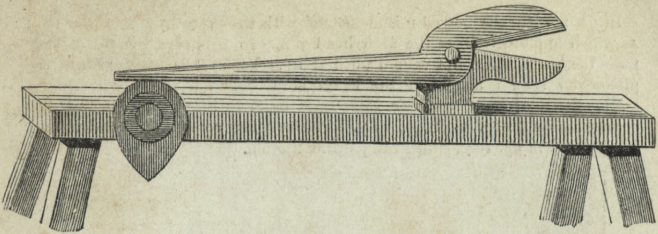


Fig. 100.

shown in the figure. In the position there shown, the arm is in its lowest position, and therefore the blades of the shears diverge as much as possible. When the wheel turns, so as to raise the movable arm, the shears will be closed. In this way, by the continual revolution of the wheel, the shears will be alternately closed and opened.

161. The treddle of the lathe furnishes an obvious example of a vibrating circular motion producing a continued circular one. The treddle acts upon a crank which gives motion to the principal wheel, in the same manner as already described in reference to the working beam and crank in the steam-engine.

162. The moving power is sometimes of such a nature as to produce an alternate motion, up and down, in a straight line. Almost every form of steam-engine, in which the piston is driven alternately from end to end of the cylinder, presents an example of this. This alternate motion is to be imparted to the working beam, which moves not in a straight line, but alternately in the arcs of a circle, of which the centre of the beam is the centre. It is, therefore, necessary, in such cases, so to connect the end of the piston rod with the head of the beam, that while the one moves up and down in a straight line, the other may move up and down in a circular arc.

Various methods have been contrived to accomplish this.

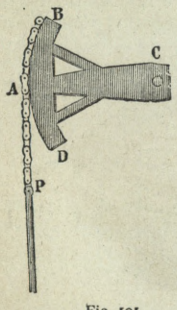


Fig 101.

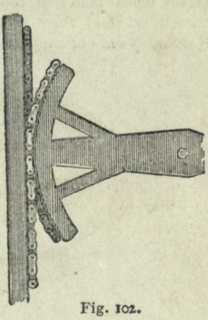


Fig. 102.

In *fig.* 101. the piston rod P is connected with the beam by a flexible chain A, which applies itself to the arch head B D. In this case the piston only pulls the beam down, but cannot push it up. When it is required that the piston-rod should act upon the beam both upwards and downwards, a double flexible chain has been sometimes used, as in *fig.* 102., or they are connected by teeth, as in *fig.* 103., but the most common method is that represented in *fig.* 104., called the parallel motion.

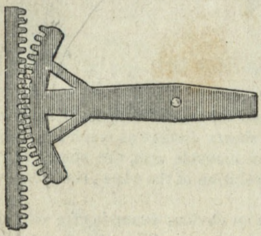


Fig. 103.

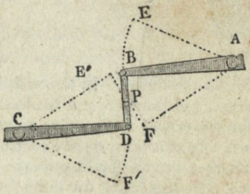


Fig. 104.

In this case the end of the beam B is connected with the end D of a vibrating rod, and the connecting bar B D is moved alternately upwards and downwards. In its motion its middle point P moves in a straight line, or very nearly so.

163. *Gimbals* is a mechanical contrivance, which bears a close relation to the universal joint. An example of it, familiar to every one, is presented by the apparatus for suspending a ship's compass (*fig.* 105.). The object is to keep the suspended body horizontal, whatever be the derangements to which the points of suspension are liable.

A brass hoop is supported by two pins, projecting from points of its external surface which are diametrically opposed to each other. Another brass hoop is supported within the former, also by two pins projecting from points of its external surface, diametrically opposed one to the other, which play in two holes made in the former hoop at the extremities of that diameter, which is at right angles to the diameter at the extremities of which the first points of support are placed.

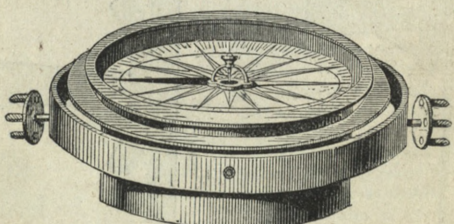


Fig. 105.

164. *The ball and socket joint*, represented in *figs.* 106, 107., has some of the properties of the universal joint. The ball moves with

Fig. 106.

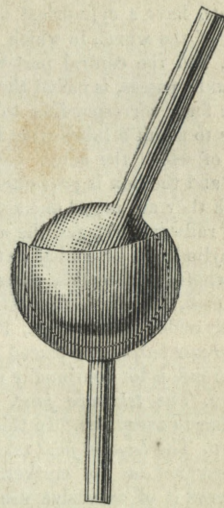


Fig. 107.

a certain play within a hollow spherical case, corresponding with it in magnitude. The action of this joint will be readily understood from the figure.

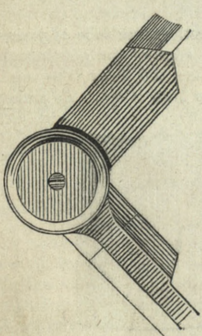


Fig. 108.

165. The joint called the *cradle joint* is that by which the legs of compasses are connected, *fig.* 100.

166. *Hinges* are obviously cradle joints, applied in a particular form.

167. *Trunnions* are strong cylindrical pins, projecting from the sides of a body, and rest in a semi-cylindrical groove, formed at equal heights in two pillars, so that the line connecting the trunnions shall be horizontal. A body such as a grindstone, thus supported, will revolve freely in a vertical plane, having the trunnions as its axis.

168. *Axles* are centres round which a wheel revolves, but wheels may turn either upon or with their axles. The wheels of ordinary

carriages turn upon their axles, the axles being strong iron bars, extending horizontally and transversely under the body of the vehicle. Their extremities, which pass through the centre of the wheels, have a cylindrical or slightly conical form. The centre part of the wheel, in which the spokes are inserted, is called the *nave*, and the central part within it, into which the extremity of the axle passes, is called the *box*. The inner surface of the box has a form corresponding to that of the axle, but a little larger, so as to admit a lubricating fluid between them, by the interposition of which the actual contact of the metallic surfaces of the axle and the box is prevented, no matter what be the pressure by which they are urged one against the other.

In railway carriages, the wheels and axle form one solid piece; the cylindrical or conical extremities of the axle project outside the wheels, and certain parts called *bearings* rest upon them. In this case, therefore, the extremities of the axle revolve with the wheels under the bearings. Reservoirs of lubricating matter, called the *grease boxes*, are placed immediately over the axles, by which the grease is let continually down upon the axles.

169. The *telescope joint*, extensively used in mechanics, is familiar to every one. In this case one tube slides within another.

170. The *bayonet joint* takes its name from the way of fastening the bayonet on the musket. Its simplicity and efficiency have rendered it of extensive use in practical mechanics. As in the telescope joint, one tube passes within another; but in this case they are held in a fixed position by means of a pin which projects from the inner tube, and passes through a rectangular opening in the outer tube.

Fig. 109. represents the position of the pin when the inner tube is pressed into the outer, until the pin comes against the edge of the opening and stops its further progress. In this position, however, the inner tube might be detached from the outer by any force tending to draw it out. To prevent

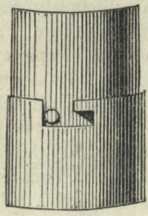


Fig. 109.

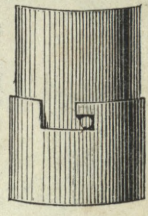


Fig. 110.

this, it is turned round its axis, until the pin enters the rectangular opening in the outer tube, as shown in *fig.* 110. It cannot be detached then without two successive motions being given to it; one round, and the other parallel to the axis of the tube.

171. When parts of mechanism usually separated require to be temporarily connected, the object is attained by *clamps*, which are made in an infinite variety of forms, according to the circumstances in which they are applied. An example of this class of contrivances is shown in *fig.* 111. The ends of the parts to be united being placed one upon the other, are introduced into the rectangular opening shown in the figure, and the screw is then turned until it urge them by a pressure sufficiently strong to hold them together.

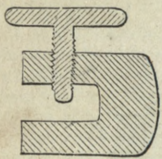


Fig. 111.

172. In the practical operation of machinery, it is frequently necessary to be enabled to suspend at pleasure, or to recommence, the motion of a wheel or wheels. This is accomplished by a class of contrivances called *couplings*.

When the motion of a wheel is imparted to another by an endless band of leather stretched tightly round them, the motion can be suspended or resumed, at pleasure, by making the band loose, and giving it the requisite tightness by pressing upon it a roller at any intermediate point between the wheels: so long as the pressure of the roller is maintained, the rotation of one wheel will be imparted to the other; but the moment the roller is removed, the communication of the motion will be suspended.

In some cases, the communication of the motion is discontinued or altered by removing the band from one or other of the wheels by lateral pressure. By this expedient, the velocity of the motion imparted may be modified. Thus, if several wheels be fixed side by side, on the same axis, having different diameters, the strap may be shifted from one to another, the velocity of rotation imparted being increased in the same proportion as the diameter of the wheel receiving the motion is diminished.

173. Couplings are sometimes constructed by providing two wheels upon the same shaft, one turning *upon* and the other *with* the shaft.

Let us suppose that the moving power keeps the wheel which turns upon the shaft constantly in revolution, but does not act upon that which turns with the shaft. In that case, it is evident that no rotation would be imparted to the shaft. Now let us suppose that the wheel W W (*fig.* 112.) is that which turns *upon* the shaft, that attached to it is a collar C embraced by a fork F at the end of a lever L, that the wheel with the collar is capable of sliding longitudinally on the shafts, and that its surface towards S′ is cut into a sort of angular teeth corresponding with similar ones formed in the face of the wheel W′ W′, which turns *with* the axle. When, by means of the lever L and the fork F, the wheel W W is moved towards the wheel W′ W′, so that the teeth are inserted the one within the other, the two wheels thus

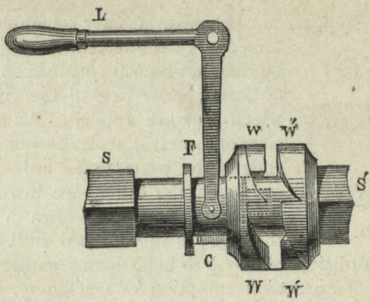


Fig. 112.

forming a single one, the wheel W W will impart its motion to W′ W′, and therefore to the shaft S S′.

On the contrary, when it is desired to suspend the motion of the shaft, the wheel W W is drawn by the lever L F towards S, and disengaged from W′ W′.

174. A class of mechanical forces, which though capable of diminishing or destroying motion, are incapable of producing it, are called *resisting forces.* Of these *friction* and *atmospheric resistance* are the most important.

175. Friction varies in its effects according to the sort of motion by which the body is affected. If a body moves with a sliding motion, the friction is much greater than if it rolls.

In general the friction is proportional to the pressure with which the rubbing surfaces act one upon the other, and is independent of the magnitude of these surfaces.

176. If the surfaces in contact be placed with their grains in the same direction, the friction will be greater than if their grains cross each other. Smearing the surfaces with unctuous matter diminishes the friction, probably by filling the cavities between those minute projections which produce the friction.

177. The pivots of pendulums or balances are usually made of steel, and rest upon hard polished stones, different surfaces being used for the purpose of diminishing the amount of friction. Brass sockets are generally used for iron axles on the same principle.

178. In the selection of lubricants, those of a viscous nature are selected, in the case of the rough surfaces of softer bodies, and those which are more fluid are applied to the smoother surfaces of harder bodies.

Thus, when metal moves upon wood, tallow, tar, or some solid grease is generally used; but when metal moves upon metal, oil is preferred; and the harder and the smoother the metal, the finer the oil. Finely pulverised plumbago is found to be a very efficient agent in diminishing friction, especially as applied to the axles of carriages and the shafts of machinery.

179. *Rollers* are used with much success as an expedient for diminishing friction.

A roughly chiselled block of stone, weighing 1080 lbs., was drawn from the quarry on the surface of the rock by a force of 758 lbs. It was then laid upon a wooden sledge, and drawn upon a wooden floor, the tractive force being 606 lbs. When the wooden surfaces moving upon one another were smeared with tallow, the tractive force was reduced to 182 lbs.; but when the load was, in fine, placed upon wooden rollers three feet in diameter, the tractive force was reduced to 28 lbs.

180. *Sledges.* — Although it is therefore obvious, on general principles, that the friction of sliding considerably exceeds that of rolling, vehicles supported on straight and parallel edges, sliding over the surface of the ground, are often found more convenient than wheel carriages. In climates where snow and frost prevail during the winter, sledges supersede all other carriages.

In New York and other cities of North America, public vehicles, such as omnibuses, hackney coaches, and all other conveyances, are taken off the

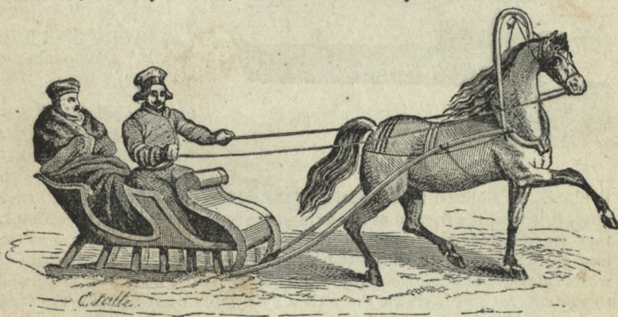


Fig. 113.

Fig. 114.

wheels, and placed upon sledges, on which they are drawn along the streets and roads. (*Fig.* 113.)

At all seasons and in all climates sledges are, for certain purposes, more convenient than wheel carriages; thus, draymen are provided with small ones to take barrels into narrow streets, where the approach of the dray would be difficult or impracticable. (*Fig.* 114.)

181. When heavy weights, such as large blocks of stone, are required to be moved through short distances, the application of rollers is attended with great advantages; but when loads are to be transported to considerable distances, the process is inconvenient and slow, owing to the necessity of continually replacing the rollers in front of the load, as they are left behind by each progressive advancement (*fig.* 115.).

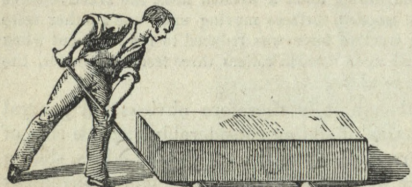


Fig. 115.

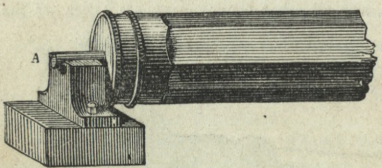


Fig. 116.

182. The wheels of carriages may be regarded as rollers which are continually carried forward with the load. In addition to the friction of the rolling motion on the road, they have, it is true, the friction of the axle in the nave; but, on the other hand, they are free from the friction of the rollers with the under surface of the load or the carriage in which the load is transported. The advantage of wheel carriages in diminishing the effects of friction is sometimes attributed to the slowness with which the axle A (*fig.* 116.) moves within the box, compared with the rate at which the wheel moves over the road; but this is erroneous. The quantity of friction does not in any case vary considerably with the velocity of the motion, but least of all does it in that particular kind of motion here considered.

183. *Castors* (*figs.* 117, 118.) placed on the feet of tables and other articles of furniture facilitate their movement from one place to another by substituting rolling for sliding friction.

184. *Friction rollers* (S S, *fig.* 119.) are sometimes interposed between an axle and its bearings, to diminish the friction attending their motion one upon the other.

185. If a carriage were capable of moving on a road absolutely free from friction, the most advantageous direction in which the tractive force could be applied would be parallel to the road; but when the motion is impeded by friction, as in practice it always is,

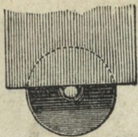


Fig. 117.

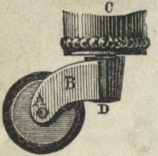


Fig. 118.

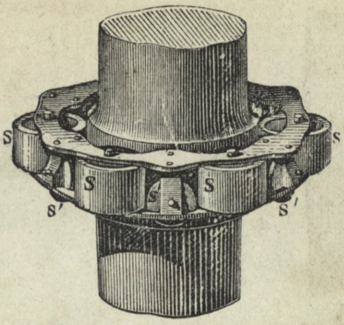


Fig. 119.

it is better that the line of draught should be inclined to the road, so that the drawing force may be exerted partly in lessening the pressure on the road, by in some degree elevating the carriage, and partly in advancing the load.

186. The most perfect modern road is the iron railway, by which the resistance due to friction is reduced to an extremely small amount.

The rolling portion of the wheels is in this case diminished by substituting for the surface iron bars called rails, supported upon cross beams of timber (*fig.* 120.), at distances apart corresponding

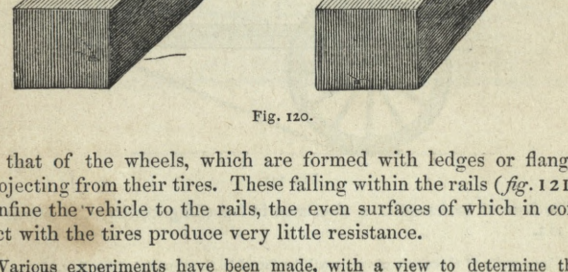


Fig. 120.

to that of the wheels, which are formed with ledges or flanges projecting from their tires. These falling within the rails (*fig.* 121.) confine the vehicle to the rails, the even surfaces of which in contact with the tires produce very little resistance.

Various experiments have been made, with a view to determine this

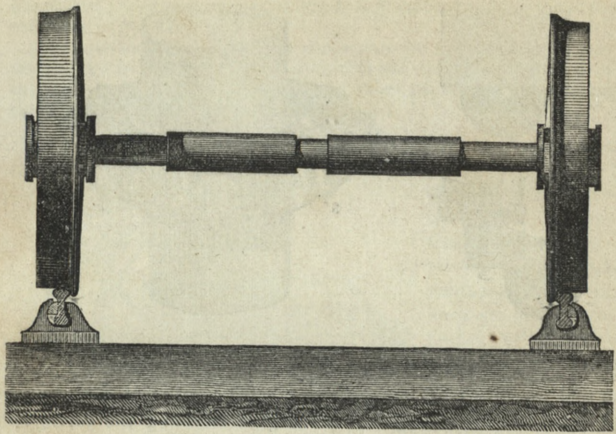


Fig. 121.

resistance; but much difficulty arises, owing to the effects of atmospheric resistance being combined with those of friction.

An extensive series of experiments was made by the author of this volume in the year 1838 * with a view to determine the amount of resistance to railway trains; the results of which showed that this resistance is much more considerable than it had been previously supposed to be, but that it depends in a great degree on the velocity, and probably arises more from the resistance of the air than from friction, properly so called.

187. Friction is generally resorted to as the most convenient method of retarding the motion of bodies, and bringing them to rest. Expedients of various forms, called *brakes*, have been contrived for this purpose.

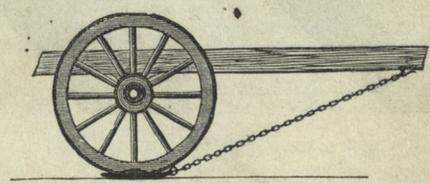


Fig. 122.

The form of brake called a *shoe*, used in travelling carriages, is shown in *fig* 122.

* The details of these experiments will be found in the reports of the Brit. Assoc. for 1838—1841.

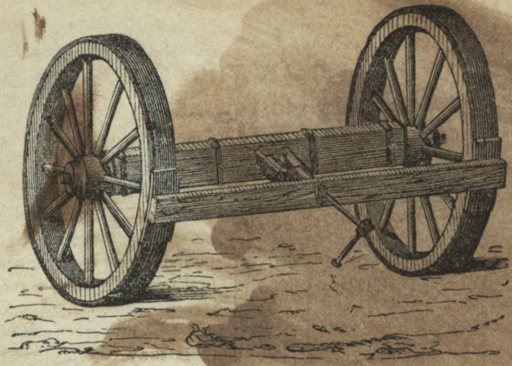


Fig. 123.

188. The brake used in diligences and other heavy vehicles on the continental roads, which is similar in principle to those used in railway carriages, is shown in *fig.* 123. Surfaces of wood are pressed against the tires of the wheels by a combination of levers pressed by the hand of the guard or conductor.

189. Friction is sometimes used as a point of resistance, as where a cable is coiled round a post to arrest the progress of a vessel (*fig.* 124.).

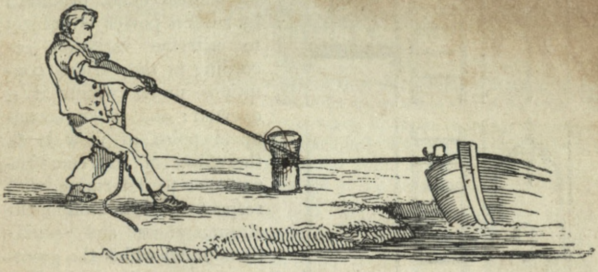


Fig. 124.

CHAP. VIII.

MOVING POWERS.

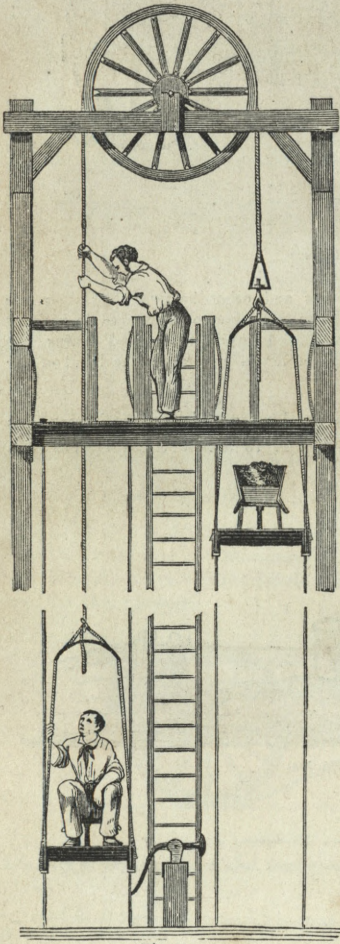


Fig. 125.

190. The natural forces used for the production of mechanical effects are very various. Those applied to move machines, sometimes called *prime movers*, are animal power, water, wind, and steam.

191. The strength of animals may be employed as a moving power in various ways: the animal may remain without change of position, working by the action of its members, as when a man works at a windlass: or it may advance progressively, transferring its own body, and carrying, drawing, or pushing a load. The mechanical effect produced by such a power is subject to extreme variation, according to the various conditions under which it is exerted; and in an economical point of view it is, therefore, of extreme importance to determine, with respect to each animal, the circumstances and conditions under which the greatest amount of useful effect can be obtained.

192. In general, however, human labour produces, in the long run, the greatest effect when it is exercised with frequent intervals of rest; and accordingly the

greatest effect is produced when an animal ascends, raising nothing but its own weight, and produces the mechanical effect by that weight itself in descending, so that the animal actually reposes in the intervals during which the mechanical effect is produced (*fig.* 125.).

The great advantage obtained by this mode of applying animal force will be apparent, when it is stated that the man who can thus produce an effect of two millions of pounds could not produce, in working at a windlass, a greater effect than a million and a quarter.

193. *Spade Labour* is one of the most disadvantageous forms in which human force can be applied.

Fig. 126.

The spade or shovel is a lever of the first or third kind, according as the one hand or the other applied to its handle is regarded as the fulcrum, the other being the power, and the earth taken up upon it being the weight. And since that part of the handle included between the two hands is always less than that between the lower hand and the earth, the force exerted is always greater than the weight of the earth raised.

194. Before the invention and improvement of the steam-engine, the force of horses was very extensively used as a moving power; and although its application to machinery is now much less frequent, it is still resorted to, especially in places where fuel is expensive.

It is found, in practice, that the most convenient method of applying horse-power to machinery is by means of a large toothed wheel fixed on a strong vertical axis, and therefore turning horizontally; to the arms of this wheel two or more horses, called machiners, are yoked in such a manner as, by travelling constantly in a circle of which the axle of the wheel is the centre, and thus pushing against their collars, to make the wheel revolve. The wheel in this case may have the form called a crown wheel, as represented in *fig.* 127., in which case it gives motion to a horizontal shaft by means of a spur-pinion or basket fixed on that shaft on which it acts; or the same object may be attained, perhaps preferably, by a bevelled wheel acting on a bevelled pinion, as explained in 128.

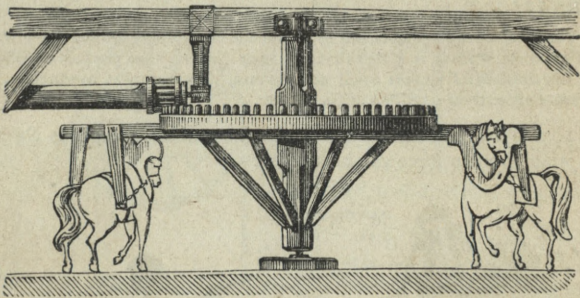


Fig. 127.

The greatest average maximum force which a horse can exert in drawing is about 900 lbs.; but when he works continuously, the force exerted must be much less than this. A good draught-horse working 6 days a week at 16 miles per day, and travelling 5 miles an hour, will bear a tractive force of about 110 lbs., and his daily labour will be equivalent to about 10,000000 lbs. raised 1 foot. A horse driving a machine, as represented in *fig.* 127., produces a somewhat less effect than a draught-horse. To preserve the animal from needless fatigue by travelling in too small a circle, the arm to which he is yoked should not be less than 20 feet in length.

195. Every one is familiar with the term horse-power as applied generally to steam-engines, as well as to water mills and other machines, but few have a definite notion of its import; horse-power thus applied, is a term merely conventional, having no reference whatever to the actual work of the animal from which its name is taken. A steam-engine which is capable of a mechanical effect per minute equivalent to 33000 lbs. raised 1 foot, is a steam-engine of 1 horse-power; and in general, if the effect produced per minute by any machine, whatever be the power which impels it, be expressed as usual by an equivalent number of pounds' weight, the number of horse-power which characterises it will be found by dividing the latter number by 33000.

196. Water-power is rendered available for the motion of machinery by intercepting its fall or progress by wheels having buckets or leaves at their circumference, upon which the water acts either by its impact or weight so as to keep them in revolution with a corresponding force.

197. The force of the atmosphere in motion is rendered avail-

able as a mover for machinery by means of arms, called sails, which are driven round in a plane nearly vertical, giving revolution to a horizontal axis.

198. When heat is applied in sufficient quantity to water, the liquid is converted into vapour which has all the mechanical qualities of air, being elastic, expansive, and compressible. Its expansive force cannot be said to have any practical limit, but the space through which it acts will decrease in nearly the same proportion as that in which its intensity increases; thus, if it be confined by a resistance equivalent to a pressure of 15 lbs. per square inch, the steam will move the resistance until it has swelled to about 1800 times the bulk it occupied as water. If the resistance is 30 lbs. per square inch, it will move it, until it has obtained a space equal to about 900 times its bulk as water, and so on.

It follows from this, that when water contained in a vessel such as a cylinder, confined by a movable piston pressing on it with a force of 15 lbs. per square inch, is converted into steam, the piston will be raised through about 1800 inches for every inch of depth of the water evaporated. A moving force would, therefore, be developed equivalent to a weight of 15 lbs. raised 1800 inches, or 150 feet; this would be in effect the same as 15 times 150 lbs., or 2250 lbs. raised 1 foot. It may, therefore, be stated in round numbers, that when a cubic inch of water is evaporated, a mechanical force is produced equivalent to a ton weight raised 1 foot high. It does not matter under what pressure the evaporation is produced, since any increase of pressure will be attended with a proportionate decrease of the space through which the resistance is moved.

199. The water, however, must in this case be regarded merely as a medium, by which the mechanical effects of heat are evolved. The real moving power is, therefore, not the water, but the combustible by which heat is produced, and that combustible being usually pit coal, it becomes a question of the highest economical importance to determine the average quantity of coal which is consumed in the evaporation of a given quantity of water, and in the consequent evolution of a given amount of moving force.

200. The consumption of coal in the evaporation of water in steam boilers varies considerably, according to the circumstances under which the fuel is applied. In Cornwall, however, where the conditions most favourable to economy are strictly observed, it has been found that in experiments conducted under circumstances of the greatest precision, a bushel of coal, that is, 84 lbs. weight, of good quality, has produced a mechanical effect equivalent to 120,000000 lbs. raised 1 foot. This must, however, be regarded as an extreme experimental result. We may take, perhaps, 100,000000 lbs. as the maximum mechanical effect attainable in regular work by the combustion of a bushel of coals.

Since it has been shown that the average maximum daily labour of a man, working under the most favourable circumstances, is 2,000000, and that of a horse 10,000000, it follows that 1 bushel of coals consumed daily can perform the work of 50 men or 10 horses.

201. It has been computed, on data such as these, that the materials of which the great pyramid of Egypt is formed, could have been raised from the ground to their actual position by the combustion of something less than 700 tons of coal. Herodotus states that 100000 men were employed for 20 years in raising this structure.

The Menai bridge consists of about 2000 tons of iron, placed at 120 perpendicular feet above the water level; its entire weight could have been raised to that height by the combustion of 400 lbs. weight of coal.

A train of coaches weighing 80 tons, and conveying 240 passengers, is drawn from Liverpool to Birmingham and back by the combustion of 4 tons of coke, the cost of which is 5*l.* To carry the same number of passengers daily, in stage coaches, on a common road, would require an establishment of 20 coaches and 3800 horses.

The circumference of the earth measures about 25000 miles; if it were begirt with an iron railway, such a train would be drawn round it in five weeks, by the combustion of about 500 tons of coke.

202. In a certain qualified sense, springs and weights may be considered as moving powers; they are, in fact, the movers in all watch and clock work. It must be observed, however, that the title of movers cannot be given to them in the same absolute sense as that in which it is applied to the several powers which we have described above.

When a watch or clock is wound up, the force which is exerted by the hand is expended in coiling up the main spring or elevating the weight, and the motion of the watch or clock from that moment until it ceases is merely produced by the spring or weight giving back, by slow degrees and during a comparatively long interval, the force which was exerted by the hand in winding them up. Strictly speaking, therefore, the moving power is in this case the force of the hand, and the spring or weight is merely the depository in which that force is collected, and from which it is given out until it is completely exhausted, and the clock ceases to move.

203. Water at a certain point of the thermal scale exhibits a striking exception to the general law of contraction by cold. Just before congelation commences, the reduction of its temperature is attended, not with contraction, but with expansion; and this expansion takes place with irresistible force. When water, having percolated into the fissures and clefts of rocks, is frozen there, the force with which it expands in the process of congelation is such that the rocks are split asunder, and fragments of enormous weight and magnitude detached from them.

This force has been sometimes applied artificially for the fracture of large masses of stone.

204. A great variety of powerful mechanical effects are produced by the chemical combination or decomposition of bodies. These phenomena, however, are generally developed under circum-

stances and conditions which render their application as mechanical agents often difficult, and sometimes impracticable. The circumstances under which the mechanical force is thus developed are generally those in which solid or liquid bodies of comparatively small dimensions are suddenly converted into gaseous bodies of great volume, the change being usually attended with a large and intense development of heat. The gases thus evolved at a high temperature, expanding with prodigious force, drive before them whatever resistances may be opposed to their dilatation.

One of the most familiar examples of this class of phenomena, and that which has been most extensively applied, is gunpowder. This substance is a mixture of nitre, charcoal, and sulphur, all in a very pure state, and in certain definite proportions; thus, in 100 lbs. weight of gunpowder there are generally 75 lbs. of nitre, 15 lbs. of charcoal, and 10 lbs. of sulphur. These proportions are subject to a small variation in different qualities of powder, which need not be noticed more particularly here.

When a spark is applied, the charcoal and the sulphur heated by it, attract the oxygen, which is one of the constituents of the nitre; and, combining with it, form gases, called carbonic oxide, carbonic acid, and sulphurous gas; while the constituent of the nitre, disengaged from the oxygen, is the gas called nitrogen, or azote. The result, therefore, of the phenomenon is the instantaneous evolution of a mixture of the four gases above named; this evolution being attended with such intense heat, that the gases are incandescent, or luminous. It is found that the gunpowder, in this process of explosion, swells into 2000 times its volume. Count Rumford found that 28 grains of gunpowder, screwed into a cylindrical space within a piece of iron, tore it asunder with a force of 400000 lbs.

205. If a piece of common raw cotton, usually called cotton wool, be steeped in a mixture composed of equal measures of sulphuric and nitric acids, and be then pressed and dried, it will, to all external appearance, be the same as before; but if it be weighed it will be found to be nearly one half heavier. The change which it has undergone is this: the cotton has lost a quantity of water which was combined with it, equal to about one third of its weight, but it has entered into combination with such a quantity of nitric acid as to give the whole a weight 50 per cent. greater than that of the original weight of the cotton.

The cotton thus prepared is highly explosive, and the effects of its explosion are explained on the same principle as those of gunpowder. It is considered by chemists that, weight for weight, the force of this substance is greater than that of gunpowder. It explodes also at a lower temperature, and, when of good quality, leaves no perceptible residuum. It is, therefore, probable that when the process of making it has undergone those improvements which it is likely to receive, it will replace gunpowder in fire-arms, as it has already done to a certain extent in the blasting of rocks.

206. The mechanical agency supplied by capillary attraction in the arts, and its use in the vegetable economy, will be explained hereafter.

207. There is no mechanical problem on which a greater amount

of intellectual ingenuity has been wasted than that which has for its object the discovery of the perpetual motion. Since this term, however, is not always rightly understood, it will be useful here to explain what the perpetual motion is not, as well as what it is.

The perpetual motion, then, which has been the subject of such anxious and laborious research, is not a mere motion which is continued indefinitely. If it were, the diurnal and annual motion of the earth, and the corresponding motions of the other planets and satellites of the solar system, as well as the rotation of the sun upon its axis, would be all perpetual motions.

To understand the object of this celebrated problem, it is necessary to remember that, in considering the construction and performance of a machine, there are three things involved: 1st, the object to which the machine gives motion; 2ndly, the structure of the mechanism; and 3rdly, the moving power, the effect of which is transmitted by the machine to the object to be moved. In consequence of the inertia of matter, the machine cannot transmit to the object more force than it receives from the moving power; strictly speaking, indeed, it must transmit less force, since more or less of the moving force must be intercepted by friction and atmospheric resistance. If, therefore, it were proposed to invent a machine which would transmit to the object to be moved the whole amount of force imparted by the moving power, such a problem would be at once pronounced impossible of solution, inasmuch as it would involve two impracticable conditions; first, the absence of atmospheric resistance, which would oblige the machine to be worked in a vacuum; and secondly, the absence of all friction between those parts of the machine which would move in contact with one another.

But suppose that it were proposed to invent a machine which would transmit to the object to be moved a greater amount of force than that imparted by the moving power, the impossibility of the problem would in this case be still more glaring, for even though the machine were to work in a vacuum, and all friction were removed, it could do no more than convey to the object the force it receives. To suppose that it could convey more force, it would be necessary to admit that the surplus must be produced by the machine itself, and that, consequently, the matter composing it would not be endowed with the quality of inertia. Such a supposition would be equivalent to ascribing to the machine the qualities of an animated being.

But the absurdity would be still greater, if possible, if the problem were to invent a machine which would impart a certain motion to an object without receiving any force whatever from a moving power; yet such is precisely the celebrated problem of the perpetual motion.

In short, a perpetual motion would be, for example, a watch or clock which would go so long as its mechanism would endure without being wound up: it would be a mill which would grind corn or work machinery without the action upon it of water, wind, steam, animal power, or any other moving force external to it.

It is not only true that such a machine never has been invented, but it is demonstrable that so long as the laws of nature remain unaltered, and so long as matter continues to possess that quality of inertia which is proved to be inseparable from it, not only in all places and under all circumstances on the earth, but throughout the vast regions of space to which the observations of astronomers have extended, the invention of such a machine is an impossibility the most absolute.

CHAP. IX.

HYDROSTATICS.

208. The part of physics which treats of the pressure of liquids is called *hydrostatics*, that which treats of their motion, *hydrodynamics*, and the practical application of the principles of hydrodynamics to the art of conducting and raising water is called *hydraulics*.

209. Although water and liquids in general are compressible, their compressibility is so extremely limited, that it may be regarded rather as a theoretical effect than one which has any practical importance, and, consequently, liquids are treated in hydrostatics and hydrodynamics as incompressible fluids.

210. In virtue of their fluidity, liquids press by their weight on all parts of the vessel which contains them, and if they are included in a close vessel, a pressure applied to the liquid at any part of the vessel is transmitted by the liquid undiminished to every other part.

Thus, if a hole having the magnitude of 1 square inch be made in a close vessel completely filled with water, any pressure exerted on a piston inserted in that hole will be transmitted undiminished to every square inch of the internal surface of the vessel. Thus, for example, if A B C D E F (*fig.* 128.) represent a glass vessel with several openings *a*, *b*, *c*, *d*, *e*, *f*, in it having pistons inserted in them, each piston having the magnitude of a square inch, a force exerted on any one of the pistons *a* will react at the same time on all the others without any diminution of its effect. If the force which presses *a* onwards be 15 lbs., each of the other pistons (*fig.* 128.) *b*, *c*, *d*, *e*, *f*, will be pushed outwards by a force of 15 lbs.

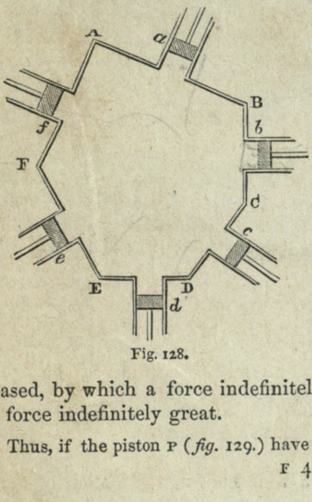


Fig. 128.

211. Upon this principle the hydrostatic paradox is based, by which a force indefinitely small may be able to produce a force indefinitely great.

Thus, if the piston P (*fig.* 129.) have the magnitude of $\frac{1}{4}$ of a square inch,

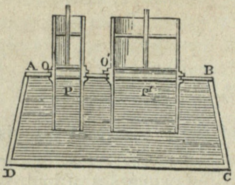


Fig. 129.

and the piston P′ have the magnitude of 1000 square inches, an inward power of 1 lb. upon P will produce an outward power of 4000 lbs. on P′.

It must, however, be observed in this and all similar cases, that in the same proportion as the effect of the force transmitted is augmented, the velocity of the part which is acted upon is diminished, so that in the case here supposed, the advance of the piston P being an inch, that of the piston P′ would be no more than the 4000th part of an inch.

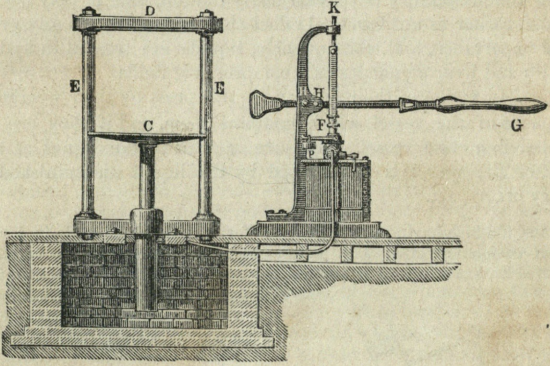


Fig. 130.

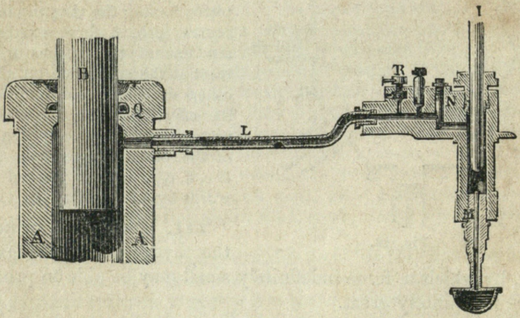


Fig. 131.

212. The *hydraulic press* is a well known application of this

principle. The machine is represented in *fig.* 130., and in section in *fig.* 131.

The plunger I (*fig.* 131.) being of small diameter, forces the water through the tube L into the comparatively large cylinder A, and reacts against the ram B, with an effect augmented in the ratio of the section of the plunger I to the section of the ram B.

213. The pressure produced upon vessels which contain liquids is everywhere proportional to the depth of the point pressed upon below the surface of the liquid, no matter what may be the direction of the surface thus acted upon.

Thus, the pressure on a square inch of the bottom of a vessel is exactly the same as the pressure upon the square inch of the side of the same vessel at the same depth, the pressure in both cases being equal exactly to that of the weight of the column of the liquid whose base is 1 square inch and whose height is equal to the depth. Since the pressure is proportional to the depth, it may easily be conceived that at great depths the pressure is very considerable.

214. If a fissure in a rock communicate with an internal cavity of any considerable magnitude, placed at some depth below the mouth of the fissure, rain percolating through, and filling the fissure above it, might produce a bursting force sufficient to split the rock. The pressure in this case, acting against the inner surface of the cavity, will be proportional to the depth of the cavity below the top of the fissure. For every foot in such difference of level, there will be a bursting pressure of 0·4328 lbs. for every square inch of the surface of the cavity.

215. In the construction of pipes for the supply of water to towns, it is necessary that those parts which are much below the level of the reservoir from which the water is supplied should have a strength proportionate to such difference of level, since they will sustain a bursting pressure of 4·328 lbs. per square inch for every 10 feet by which the level of the river exceeds in height that of the pipe.

A pipe, the diameter of whose bore is 4 inches, has an internal circumference of about 1 foot, and the internal surface of 1 foot in length of such a pipe would measure a square foot. If such a pipe were 150 feet below the level of the reservoir, the bursting pressure which it would sustain upon 1 foot of its length may be calculated as follows:—

	lbs.
Pressure at 100 feet deep - - - - -	6232
" 50 " - - - - -	3116
Pressure at 150 " - - - - -	9348

Thus, such a pipe should be constructed of sufficient strength to bear with security nearly five tons bursting pressure on each foot of its length.

216. If an empty bottle tightly corked be sunk in the sea, the pressure of the surrounding water, when the depth is sufficient, will either break the

bottle or force the cork into it. If the bottle have flat sides, it will be broken; if it be round, its form being stronger, the cork will be forced in.

If a piece of wood which floats on water be sunk to a great depth in the sea, and held there for a certain time, the great pressure of the surrounding liquid will force the water into the pores, the effect of which will be to increase its weight so that it will no longer be capable of floating or rising to the surface.

Divers plunge with impunity to certain depths, but there is a limit below which they cannot live under the intense pressure. It is probable, also, that there is a limit of depth below which each species of fish cannot live.

217. It is in consequence of this relation between the pressure and the depth that liquids always have a level surface, and that the surface of liquids in any two or more vessels which communicate with each other must always be at the same level, for if any two parts of the surface of a liquid, whether in the same or in different vessels communicating with each other, were at different levels, they would exert different pressures downwards, and that which has the higher level prevailing over that which has the lower, would press it upwards, and this would continue until the surfaces would come to the same level.

218. This property of liquids is so nearly a self-evident consequence of their fundamental property, that it is difficult to demonstrate it. It is nothing more than a manifestation of the tendency of the component parts of a body to fall into the lowest position which the nature of their mutual connection, and the circumstances in which they are placed, will admit. Mountains do not sink and press up the interjacent valleys, because the cohesive principle which binds together the component parts of their masses, and those of the crust of the earth upon which they rest, is opposed to the gravity of their parts, and is much more powerful; but if this cohesion were dissolved in the stupendous masses, — for example, if the Alps or the Andes were liquefied,— these ridges would sink from their lofty eminences, and the circumjacent valleys would rise, a momentary interchange of form taking place; and this undulation would continue, until the whole mass would settle down into a uniform level surface. All inequalities, therefore, which we observe on the surface of land, are due to the predominance of the cohesive over the gravitating principle; the former depriving the earth of the power of transmitting equally and in every direction the pressure produced by the latter.

On the other hand, if the sea, when agitated by a storm, were suddenly solidified, the cohesive principle being called into action, the mass of water would lose its power of transmitting pressure, and those inequalities which in the liquid form are fluctuating would become fixed; a wave would become a hill, and an intermediate space a valley.

219. The apparatus represented in *fig.* 132. is adapted to explain experimentally these facts. A, B, C, D, E are glass vessels of different shapes, each terminating at the bottom in a short tube which is inserted into a hollow box. In each of these short tubes is a stop-cock K.

When the cocks are all open, a communication between the five vessels is established through the intervention of the box; but each or all of the vessels can be insulated by closing the cocks.

Fig. 132.

Let the stop-cocks be all closed, and let water be poured into the vessels, so as to stand at different levels, the case below being previously filled with water. If all the cocks be now opened, it will be observed that the higher levels will gradually fall, and the lower ones will rise until all become uniform. If the stop-cocks be again closed, and water be poured into some of the vessels, so as to render the levels again unequal, the same equalisation would take place on again opening the stop-cocks.

220. *Fountain Ink-bottles* (*fig.* 133.) depend upon this principle.

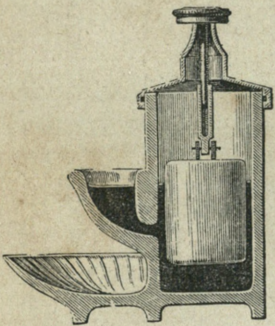


Fig. 133.

When the plunger descends the ink rises, always standing at the same level within and without the ink-bottles.

221. The methods of conducting a canal through a country which is not a dead level depend upon the same property. By expedients called *locks* (*figs.* 134. and 135.) a canal can be continued along any declivity. If it were cut on an inclined surface, without such an expedient, the water would run towards the lower extremity and overflow the bank, leaving the higher end dry. A channel of any considerable length, having even a gentle and gradual slope, would be attended with this effect. In the formation of a canal, therefore, its course is divided into a series of levels of various lengths according to the inequalities of the country through which it passes; these levels communicate one with the other by locks, by means of which vessels passing in either direction are raised or lowered with perfect ease and safety.

222. When vessels containing liquids are supplied with spouts, such as those attached to tea-pots, coffee-pots, kettles, watering-pots, and the like, the extremity of the spout must always be

above the top of the vessel when the vessel stands erect, since otherwise the vessel could not be filled; for as soon as the liquid

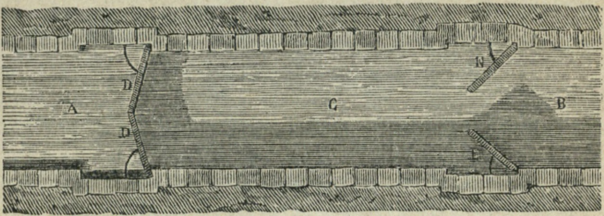


Fig. 134.

poured into it has risen to the level of the top of the spout, any more liquid which might be poured in would flow out of the spout.

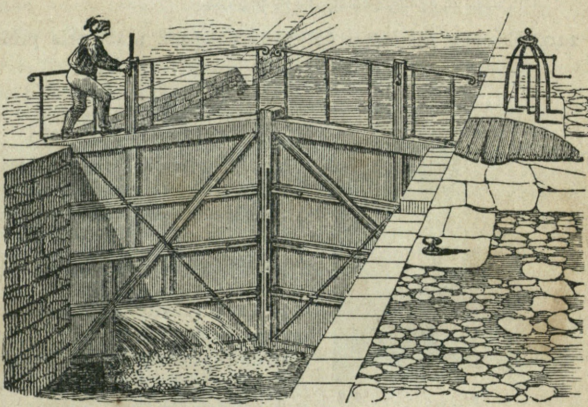


Fig. 135.

Liquids are discharged from a vessel having a spout by inclining the vessel in such a manner that the mouth of the spout shall be below the level of the liquid in the vessel.

223. *Levelling Instruments* (*fig.* 136.) depend upon the principle here explained.

The liquid in the two tubes B C communicating will be at the same level, and the floats through which the observer looks are necessarily also at the same level. It follows, therefore, that the point D is at the same level with the points B and C.

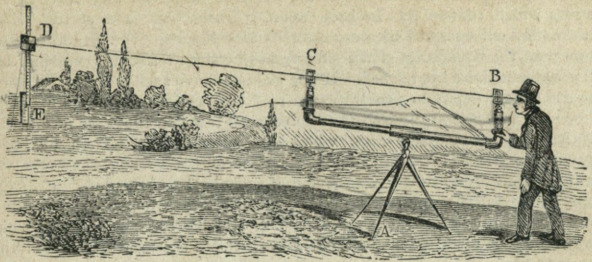


Fig. 136.

224. The play of the property in virtue of which liquids maintain their level, explains an infinite variety of important and interesting phenomena attending the circulation of water on the surface of the globe. By the natural process of evaporation, the clouds become charged with vapour, and are attracted by the lofty ridges of mountains, and all other elevated parts of the land, round which they collect, and upon which they deliver their contents.

The water thus deposited upon the highest parts of the globe has a constant tendency, by reason of the quality to which we refer, to return to the general level of the sea, and in finding its way thither gives rise to the phenomena of streams, rivers, cataracts, lakes, springs, fountains, and in a word, to all the infinite variety of effects attending the movement of water which are witnessed throughout the world.

If the waters which fall from the clouds encounter a soil not easily penetrable, they collect in rills, and form streams and rivulets, and descend along the sides of the elevations, seeking constantly a lower level; they encounter in their course other streams, with which they unite, and at length swell into a river; they follow a winding channel, governed by the course of the valleys and lower parts of the land. Sometimes widening and spreading into a spacious area, they lose the character of a river, and assume that of a lake; then again, being contracted, they recover the character of a river, and after being increased by tributary streams on the one side and on the other, they at length attain their final destination, restoring to the ocean those waters which had been originally drawn from it by evaporation. Throughout the whole of these phenomena, the principle in operation is the tendency of liquids to maintain their level.

But it sometimes happens that the rains on mountainous summits encounter a soil easily penetrable by water. In such cases, the liquid enters the crust of the earth, which it often penetrates to great depths.

Sometimes it encounters strata which are impenetrable, and finds itself walled, so to speak, into a subterranean reservoir. In this case, the liquid is subject to a hydrostatic pressure, arising from the column of water extending from the reservoir to the upper surface, through the veins and channels through which the reservoir has been filled.

This pressure sometimes forces the water to break its way through the strata which confine it. In such cases, it gushes out in a spring, which ultimately enlarges and becomes the tributary of some river. In other cases, however, the boundaries of the subterranean cistern resist this pressure, and the water is there imprisoned. If the ground above such a cistern be bored to a sufficient depth to penetrate the roof of the cistern, the liquid having free exit, will rise in the well thus bored until it attain the same level which it has in the channels from which the subterranean cistern has been supplied. If this level be above the surface of the ground, the water will have a tendency to rush upwards, and, if restrained and regulated in its discharge by suitable means, it may be formed into a fountain, from which water will always flow, by simply placing a valve or cock, or from which water may be made permanently to project itself upwards in various forms, so as to produce *jets d'eau.*

If the level of the source, however, be a little less than that of the mouth of the pit which has been dug, then the water will rise to such level, and stand there, forming a well. If the original level be considerably below that of the mouth of the pit, then the water will not rise in the pit beyond a certain height corresponding to the level of its source; and in this case a pump is introduced into the pit, and water is raised in a manner which will be explained hereafter.

225. When a solid body is immersed in a liquid it would remain at rest, neither rising nor sinking, if it had the same weight as the liquid whose place it occupies. This is evident because the liquid whose place it occupies would thus have remained at rest. If the solid body have greater weight than the liquid it displaces, it will sink. If it have less weight, it will rise to the surface.

If a body have less weight, bulk for bulk, than a liquid, it will float upon it, the part immersed displacing just as much liquid as is equal to the weight of the body.

226. It appears, therefore, that a solid is buoyant in a liquid in proportion as it is light and the liquid heavy. Thus the same solid is more buoyant in quicksilver than in water; and in the same liquid, cork is more buoyant than lead.

A solid which will float in one liquid will sink in another: thus glass sinks in water, but floats in quicksilver; ebony sinks in spirits of wine, but floats in water; ash and beech float in water, but sink in ether. All these effects are explained by the fact, that in each case the solid sinks or rises according as it is heavier or lighter, bulk for bulk, than the liquid.

227. A block of stone or other heavy substance is more easily raised at the bottom of the sea than the same block would be on land; because, immersed in the sea, it is lighter by the weight of its own bulk of sea-water than it would be on land.

In building piers and other subaqueous works this is rendered manifest. Those who thus work seem endowed with supernatural strength, raising with ease, and adjusting in their places, rocks which they would vainly attempt to move above water. After a man has worked for a considerable time under a diving-bell, he finds, upon returning to the upper air, that he is apparently weak and feeble; everything which he attempts to lift appears to have unusual weight, and the action of his own limbs is not effected without inconvenience.

228. The human body does not differ much from the weight of its own bulk of water; consequently, when bathers walk in water chin-deep, their feet scarcely press on the bottom, and they have not sufficient purchase upon the ground to give them stability. If they are exposed to a current or any other agitation of the fluid, they will be easily taken off their feet.

When air is drawn into the lungs, the body becomes enlarged by its distension; and when it is expired, the dimensions of the body are again diminished. The weight of the body is so nearly equal to that of its own bulk of water, that this change of magnitude, small as it is, is sufficient to make it alternately lighter and heavier than its own volume of water. When a bather, therefore, inspires so as to fill his chest with air, he becomes, in a slight degree, lighter than water, and his head rises above the surface; when, on the other hand, he expires, the body, contracting its dimensions without changing its weight, becomes heavier than water, and he sinks. Without some action to counteract this oscillation, the alternate sinking and rising would produce inconvenient effects; but this may be prevented by a slight action of the hands and feet, which resists the intermitting tendency to sink.

The facility with which different individuals are able to float or swim varies according to the proportion which the lighter constituents of the body, such as the softer parts, bear to the heavier, such as the bones.

229. A body composed of any material, however heavy, may be so formed as to float on a liquid, however light. The method of accomplishing this is by giving to the solid such a shape that, when immersed in the liquid, some space within the vessel, below the external surface of the liquid, will be occupied by air or some other substance lighter than the liquid.

Thus, if a tea-cup be placed with its bottom downwards in water it will float, and if water be poured into it, it will still float, but it will be found that the surface of the water in the tea-cup will always be below that of the external water, the air which occupies the difference of the levels producing the buoyancy.

A ship may be composed of materials heavier, taken collectively, than their own bulk of water, and nevertheless it floats, because its hull contains air and other substances much lighter than water; but if such a ship spring a leak it will sink.

Vessels laden with cork, certain sorts of timber, and other substances lighter, bulk for bulk, than water, will often become water-logged, but will still float, because the vessel and the cargo taken together are lighter than their own bulk of water.

An iron boat will float with perfect security, and if it be formed of double plates of metal, enclosing a sufficient hollow space between them, nothing can sink it, so long as such casing remains uninjured.

230. The bodies of certain species of animals are much lighter than their own bulk of water. Water-fowl, in general, present examples of this, their plumage contributing much to their buoyancy. Fishes have the power of changing their bulk by the voluntary distension of an air-vessel which is included in their organisation. By these means they can render themselves at will lighter or heavier than their own bulk of water, and rise to the surface or sink to the bottom. As fishes cannot obtain the air necessary for this voluntary inflation from a surrounding medium, they are provided with an

apparatus by which they can generate gas for the purpose. This gas is in general not similar to atmospheric air. In such species of fish as live near the surface, it is found to be generally pure azote or hydrogen; in those species which inhabit strata of the deep having a depth of from 3000 to 4000 feet, the gas generated consists of 90 parts of oxygen and 10 of azote.

231. When a liquid issues from an orifice in a side of a vessel, its velocity of efflux will be equal to that which a body will acquire in falling freely from the surface of the liquid to the level of the point of efflux, and if the liquid issue upwards in a *jet d'eau*, it would rise to a height corresponding with the level of the surface, except so far as the resistance of the atmosphere would interfere with the phenomenon. This is illustrated in *fig.* 137.

232. *Ornamental Waterworks.* — The effects of the various forms of *jets d'eau*, by which artificial fountains are constructed, depend altogether on the principles which have here been explained. The reservoirs from which the water is supplied are always established upon an elevation, the level of which is considerably higher than that of the fountains. The pipes conducting the water from the reservoirs are of such dimensions as are capable of supplying the necessary quantity of water in a given time, and so as not to diminish its force injuriously. The *jets d'eau* are produced by inserting, at proper places in the ornamental works of the fountains, *ajutages* in directions proper to produce the desired effects. Theoretically, the water issuing from a vertical *jet d'eau* ought to rise to the level of the reservoir, but it is prevented from rising even nearly to that elevation by the loss of force due to the various causes which have been explained.

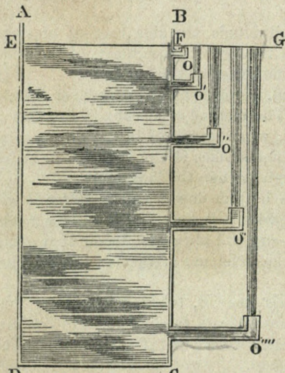


Fig. 137.

It will be evident, from what has been stated, that the less distant the reservoirs are from the fountains, the less force will be lost; circumstances, nevertheless, sometimes render it unavoidable to establish them at a considerable distance. Thus the celebrated waterworks at Versailles are supplied from an artificial reservoir erected on the heights of Marly. This reservoir is filled with water driven into it by a steam-engine erected on the banks of the Seine, through a large iron pipe carried up to it upon an inclined plane.

The waterworks of the Crystal Palace, Sydenham, are supplied from a reservoir erected in the gardens at a considerable altitude above the level of the fountains. This reservoir receives its supply, by means of a steam-engine, from a well sunk in the gardens.

233. The ancients used the flow of water issuing from a pipe as a measurer of time. For this purpose, however, it was necessary that the discharge should be perfectly uniform, and, consequently, that the level of the water in the cistern from which the discharge pipe issues should be constant. This invariable level was obtained by a very simple expedient, shown in *fig.* 138., where A is the cistern, and C the pipe from which a uniform discharge is maintained.

The cistern is fed by a cock B, which discharges more water than that which issues from C, and consequently the level of the water would continually rise in the cistern; this, however, is prevented by the discharge pipe D, so that the level of the water is continually maintained at the point from which that spout issues.

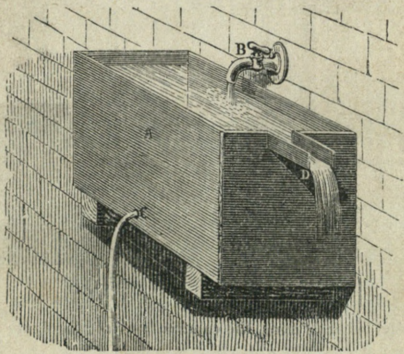


Fig. 138.

If the stream issuing from the spout C be received in a tall cylindrical vessel, it is evident that the level of the surface in such a vessel will rise at a rate proportionate to the quantity of water discharged per minute from the pipe C; and since this discharge is rendered uniform by the means above explained, the ascent of the surface of the water in the cylindrical vessel will be also uniform.

If the latter vessel, being made of glass, had a divided scale engraved upon it, each of the divisions of which would correspond to a given interval of time, an hour for example, it would serve as a chronometer, the successive hours being indicated by the coincidence of the level of the water with the successive divisions of the scale.

One of the methods of constructing such a chronometer, adopted among the ancients, is shown in *fig.* 139, where the base of the column is the reservoir into which the uniform discharge of water takes place. The two figures which appear on the base are supported upon a float resting on the surface of the water, and rising with it. One of the figures holds a wand, which

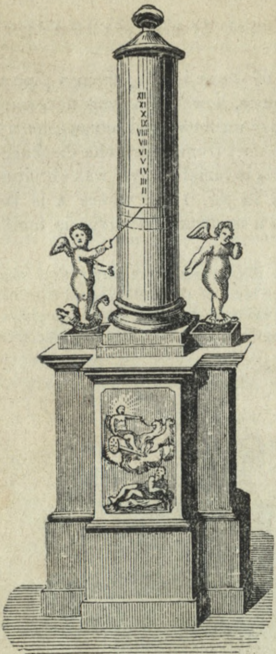


Fig. 139.

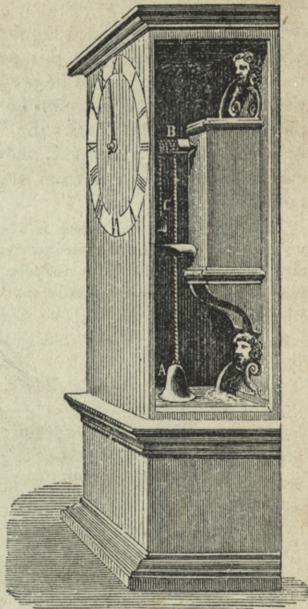


Fig. 140.

points to a divided scale upon the column, and as the figure is raised with the float, the wand points to the successive hour lines.

Another form of clepsydra is shown in *fig.* 140., where the lower discharge is rendered uniform by the maintenance of a constant level in the cistern above it.

234. It has been ascertained by geologists, that the crust of the globe consists of strata composed of various mineral matters, which succeed each other in a certain order. Some of these are such that water can easily percolate them, while others are impervious to it. A subterranean sheet of water may be included between two impervious strata, and may be there confined under an intense pressure. If a hole be bored downwards from the surface, (*fig.* 141.) until it reach such a subterranean sheet of water, the water will be forced upwards along the hole to the surface, and may rise to a great height above the surface, in a jet like that of a great fountain. Thus, if the level of the subterranean water be at D, the jet would rise to the height H, except so far as the resistance of the air would interfere with it.

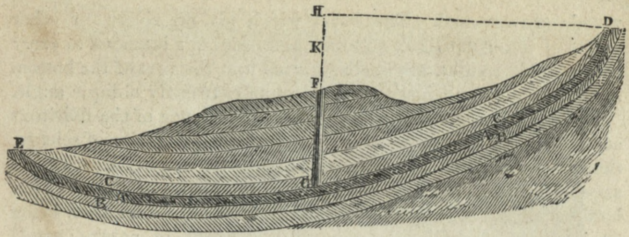


Fig. 141.

235. A fountain produced in this manner is called an *Artesian well*, the practice of constructing such wells having prevailed for many ages in the province of Artois, in France, and the discovery of the expedient having been assigned to that locality. It is known, however, that such wells were constructed in ages much more remote in Egypt and in the East.

Owing to the great depth to which in most cases it is necessary to sink for these wells, the shafts are made of very small transverse diameters; they are, indeed, more properly holes than shafts, their entire diameter not exceeding from 12 to 18 inches. They are bored by means of peculiar tools, by which, while the matter drawn out of them is taken up, a hollow iron cylinder is let down, so as to line the surface of the shaft, and effectually prevent the sides from falling in. The depths to which these shafts have been driven in some cases is truly surprising. In the well-known Artesian well on the plain of Grenelle, near Paris, the shaft is sunk to the depth of nearly 1800 feet, and the water rises with such a force that, when received in a vertical tube, it would rise 120 feet higher.

The well of Grenelle is said to be capable of supplying water at the rate of about 14½ millions of gallons per day.

236. The effect produced upon the resistance offered to a body moving through a liquid, by the obliquity of the different parts of the surface of such a body to the direction of the motion, forms an important element in the solution of the problem for determining, under different conditions, the shape of the solid moved. A problem which has attained great celebrity in the history of mathematics, is one in which it was required to determine the form which should be given to a determinate mass of solid matter, so that it might move through a liquid with the least possible resistance. The form thus determined is known in geometry as the solid of least resistance.

237. Nearly similar conditions attend the solution of all the problems which are presented in naval architecture. It is this principle which causes the length of the vessel to be presented in the direction of the motion, and which determines the shape of the prow under the various conditions to which different classes of

vessels are exposed. The boats which ply on rivers, or other sheets of water not liable to much agitation, nor intended to carry considerable freight, are so constructed that the part of the bottom immersed moves against the liquid at an extremely oblique angle.

238. It has been often mentioned, as an instance of the felicitous accordance of the works of nature with the principles of science, that the form given by mathematicians as the solid of least resistance accords exactly with the forms of the bodies of fishes. This, however, is not strictly the case; and if it were, so far from being an instance of skill and design in the works of nature, would manifest a certain degree of imperfection.

The solid contemplated in the celebrated problem adverted to has no other function to discharge except to oppose the resistance of the fluid, and the question is one of a purely abstract nature, viz., what shape shall be given to a body, so that, while its volume and surface continue to be of the same magnitude, it may encounter the least possible resistance in moving through a fluid? It must be apparent that many conditions must enter into the construction of an animal, corresponding to its various properties and functions, independently of those in virtue of which it employs itself to cleave the water.

239. *Propulsion of Vessels by Paddle-wheels.* — The power of steam has been applied to the propulsion of vessels, either by paddle-wheels, or by submerged screw propellers.

Paddle-wheels are attached to a horizontal shaft which passes across the vessel, having cranks formed at or near its centre, which receive motion from steam-engines erected in the vessel itself; the wheels, being fixed upon the ends of the shaft, revolve with it. These wheels consist of a certain number of straight arms which diverge from their axes, to the ends of which flat boards, called paddle-boards, are attached, the surfaces of which are at right angles to the plane of the wheel, and their edges directed to its centre (*fig.* 142.).

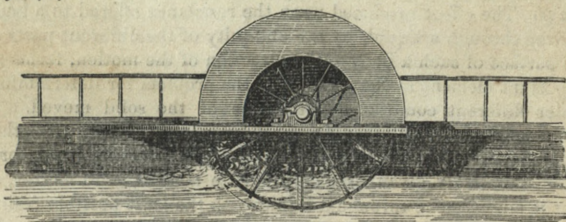


Fig. 142.

240. These causes of inefficiency and waste of the propelling power have of late years turned the attention of steam-boat projectors and engineers to the discovery of some form of subaqueous propeller which would be exempt from such disadvantages, and the result has been the successful application of that particular form of submerged propeller called the *screw*.

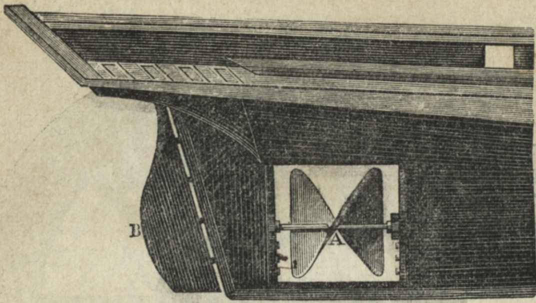


Fig. 143.

To understand the manner in which this propeller acts, let us imagine a large screw to be extended along the vessel under the keel. If the water in which this screw is submerged were solid, it is evident that, by turni ng the screw round in one direction or the other, it would move through the

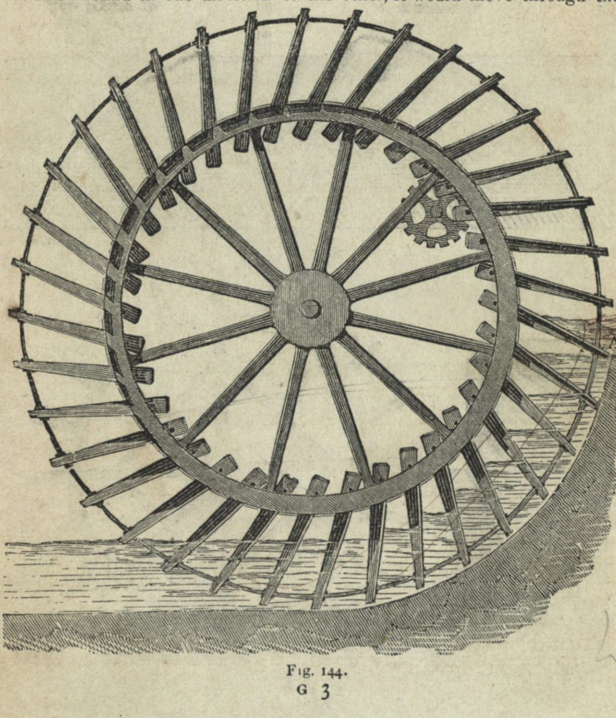


Fig. 144.

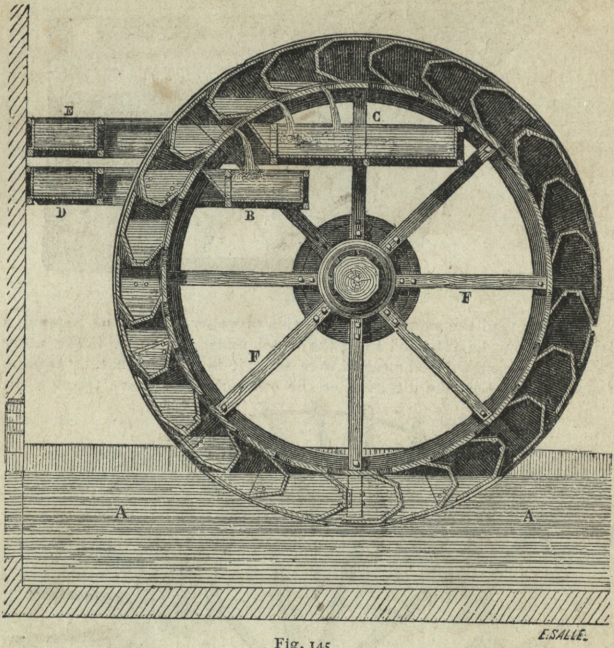


Fig. 145

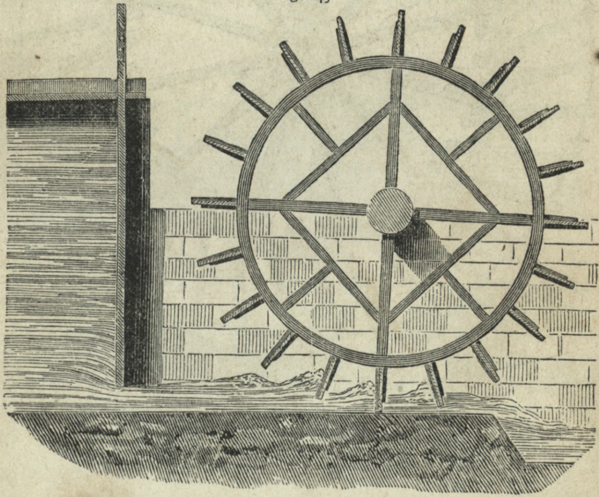


Fig. 146.

water, carrying the vessel with it, the space through which it would move in each revolution being equal to the interval between two contiguous threads of the screw. In fact, in such a case the water would play the part of a fixed nut in which the screw would turn; and in such case the screw would move forward or backward through the nut, according to the direction in which it is turned, in the manner here stated.

But the water, though far from being fixed in its position like a solid nut, offers, nevertheless, a certain resistance to the screw. If it yielded to the screw without reaction, the water would be moved backwards by the screw exactly as a movable nut is when the screw is fixed. But the water having considerable inertia, though it yields to the screw, reacts upon it, and such reaction produces a corresponding impulsion in the vessel.

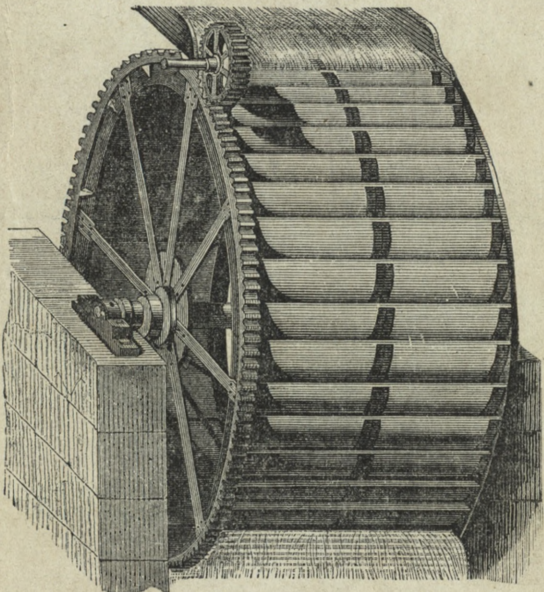


Fig. 147.

The screw is usually formed by constructing a helical vane, turning spirally round an axle, which passes vertically over, and parallel to, the keel, and is placed immediately in front of the rudder.

241. When the height to which water is to be raised is not very considerable, its elevation is sometimes effected by wheels, two varieties of which are shown in *figs.* 144. and 145.

242. When water is used as a moving power, the most common method of applying it is by directing its force against the vanes of wheels, or discharging it into buckets, formed on the circumference

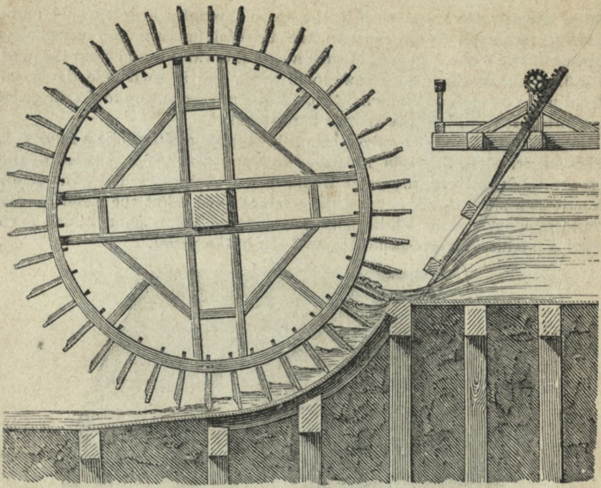


Fig. 148.

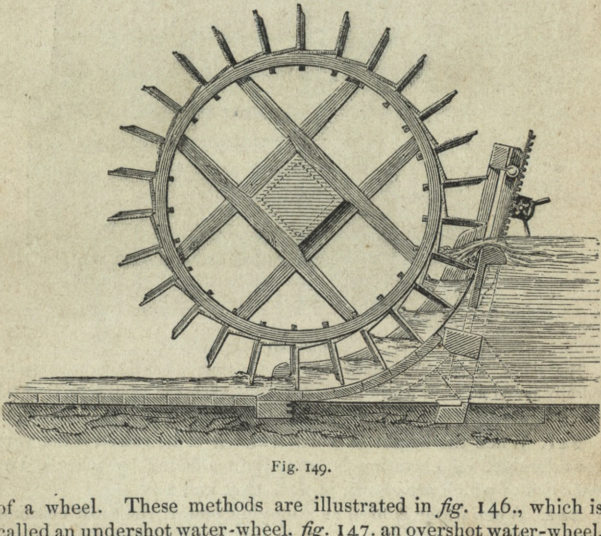


Fig. 149.

of a wheel. These methods are illustrated in *fig*. 146., which is called an undershot water-wheel, *fig*. 147. an overshot water-wheel, and *figs*. 148. and 149. are called breast wheels.

243*. **Specific gravity.**—When substances are compared one with another in reference to their weight, one is denominated heavier or lighter than another, without any special reference either to the bulk or weight of any particular quantity of the substance in question.

Thus, when we say cork is lighter than oak, and mercury is heavier than water, we speak intelligibly, although it be true that a particular mass of cork may be found which is heavier than a particular quantity of oak, and a certain mass of water may be heavier than another particular mass of quicksilver. It is, however, implied in such estimates, that they refer to equal volumes of the two substances which are thus compared as to weight. When we say that cork is lighter than oak, we mean that a piece of cork is lighter than a piece of oak of the same size: and when we say that water is lighter than mercury, we mean the observation to apply to equal measures of the two liquids.

A substance is sometimes said to be heavy or light without express reference to any other substance: thus air is said to be light, and lead heavy. A comparison is, however, here tacitly implied. It is meant that air is lighter, and lead heavier, bulk for bulk, than the average of the substances that fall under common observation. This use of positive terms to express comparative qualities prevails in all applications of language: thus we say of a certain individual that he is very tall, and of a certain house that it is very high; meaning that the man is taller than the average of men, and the house higher than the average of houses.

244*. The absolute weight of a body is that of its entire mass, without any reference to its bulk; the relative weight is the weight of a given magnitude of the substance compared with the weight of the same magnitude of other substances. The term weight is commonly used to express the absolute weight, while the relative weight is called *specific gravity*. This denomination of relative weight implies that bodies of different species have different weights under equal volumes. Thus, a cubic inch of cork has a weight different from a cubic inch of oak or of gold; a cubic inch of water contains a less weight than a cubic inch of mercury.

Each different species of body has a different weight corresponding to the same bulk; and hence the name specific gravity, which expresses the weight of a given bulk.

245*. It happens that a cubic foot of water at the common temperature of 60° weighs exactly 1000 oz. Taking, then, the specific gravity of water to be expressed by 1·000, that of any other liquid or solid body will be also expressed by the number of ounces in a cubic foot divided by 1000. Thus, a cubic foot of pure quicksilver at the same temperature weighs 13,580 oz., and a cubic foot of iron 7788 oz. The specific gravity of the former is therefore 13·580, and that of the latter 7·788.

246*. The specific gravities of gases and vapours are in like manner referred to air as the unit. If a cubic foot of any gas be twice or half the weight of a cubic foot of air under like conditions of temperature and pressure, its specific gravity will be 2 or ½.

CHAP. X.

PNEUMATICS.

243. If air be compressed by any mechanical force, its volume will be diminished in the exact ratio of the compressing force. Thus the atmosphere around us, which exercises a pressure on the surface of all bodies in contact with it, amounting to 15 lbs. per square inch, if submitted to twice the pressure will be reduced to half its volume; if submitted to triple the pressure, it will be compressed into a third of its volume, and so on. This principle is known in physics as *Mariotte's law*, having been first demonstrated by that philosopher.

244. It is the weight of the atmosphere which supports the column of mercury in the barometer, and this column is accordingly the measure of its weight. Thus a column of air, extending from the surface of the earth to the summit of the atmosphere, and having a square inch for its base, will have a weight equal to the column of mercury, also having one square inch for its base, and a height equal to that of the barometric column.

245. The method of constructing a barometer is illustrated in *fig.* 150.

A glass tube closed at one end and open at the other, is filled with purified mercury, proper precautions being taken to exclude air bubbles. The top being then stopped by the thumb, the tube is inverted and the open end plunged in a cistern of mercury. On removing the thumb the column in the tube does not, as might be expected, fall to the level of the mercury in the cistern, but will be sustained at a height of 29 or 30 inches above that level. The unoccupied space in the tube above the column of mercury is what is called a Torricellian vacuum, from Torricelli, the inventor of the barometer. It is the most perfect vacuum known, though not a vacuum in the absolute sense of the term, since a mercurial vapour of extremely small density fills it.

246. The column of mercury is sustained in the tube by the pressure of the atmosphere acting upon the surface of the mercury of the cistern, pressing the mercury upwards in the tube. That this is the case is proved in the following manner: —

Let the top of the tube be broken so as to admit the atmosphere above the mercury: in that case the mercury in the tube will immediately fall to the level of the mercury in the cistern.

247. A further demonstration of this is derived from the following remarkable experiment. If a barometer be carried upwards in the atmosphere it

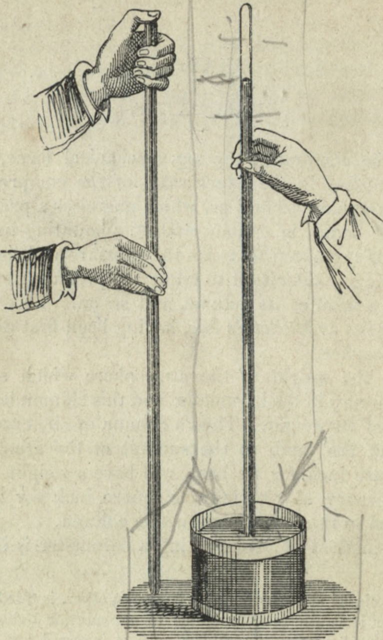


Fig. 150.

will have less and less atmosphere above it, and the surface of the mercury in the cistern will be submitted to less and less pressure, and will consequently support a less and less column of mercury in the tube. In accordance with this it is actually found that when a barometer is carried upwards, the column of mercury in the tube gradually becomes less and less, and this change is so regular that the height to which the barometer has been carried is indicated with great precision by the diminution of the column of mercury in the tube, and in this manner the barometer becomes an instrument for measuring heights.

248. By this means the heights of mountains are measured, when adventurous travellers scale them. The heights to which balloons ascend are also ascertained in the same manner.

249. Barometers are of various forms, according to the expedients adopted for indicating the variation of the height of the mercury. The vertical barometer is shown in *fig.* 151., and the

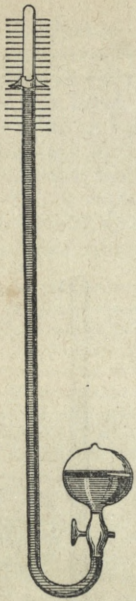


Fig. 151.

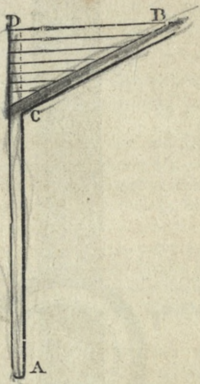


Fig. 152.

diagonal in *fig.* 152., where the upper part of the tube is inclined, so as to increase the space through which the mercury plays. Another form of barometer, called the wheel barometer, is shown in *fig.* 153. In this case, the variation of the column produces a movement of an index or needle upon a graduated scale. The manner in which this is accomplished is illustrated in *fig.* 154.

250. That the height of the atmosphere is subject to variation is proved by the fact, that the height of the mercurial column which balances it in the barometer, is subject to variations within certain small limits, that height never exceeding 31, and rarely falling below 28 inches.

Two cubic inches of mercury weigh in round numbers 1 lb. avoirdupois; consequently, when the height of the barometer is 30 inches, the column of mercury sustained in the barometer, if it had a square inch for its base, would weigh 15 lbs.; and since this balances the atmospheric pressure, it follows that the pressure of

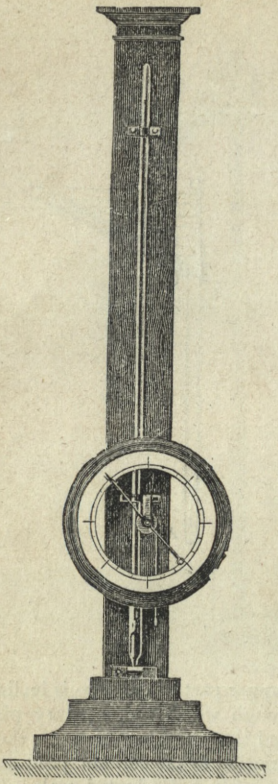


Fig. 153.

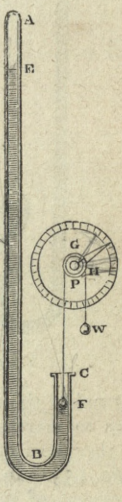


Fig. 154.

the atmosphere, when the barometer is at 30 inches, is 15 lbs. per square inch.

But the air possesses, in common with all other fluids, the faculty of transmitting pressure equally in every direction; consequently it follows, that every object exposed to the atmosphere is pressed upon every part of its surface with a force amounting to 15 lbs. per square inch.

The surface of a human body of average size measures about 2000 square inches. Such a body, therefore, sustains a pressure from the atmosphere amounting to 30000 lbs., or very nearly 15 tons.

251. It might be expected that the great pressure to which all bodies surrounded by the atmosphere are exposed would produce conspicuous effects, in crushing, compressing, or bursting them; whereas it is found that even the most delicate textures are not affected by it. A bag made of the lightest and finest tissue partially filled with air, is practically subject to no external pressure; its sides, though loaded with an enormous pressure, do not collapse. This is explained partly by the equality of the pressure which is directed upon it on all sides, and partly by the resistance produced from within, by the elasticity of the air contained in it.

The same circumstances explain the fact that animals are neither obstructed in their movements, nor crushed by the enormous pressure to which their bodies are subjected. The atmosphere pressing them equally in every possible direction, laterally and obliquely, upwards and downwards, has no tendency to impel them in any one direction rather than another, and consequently offers no other resistance to their motion than is produced by the inertia of the atmosphere itself. The internal pores of their bodies being filled with fluids, both liquid and gaseous, producing a pressure outwards exactly equal to the external pressure of the air inwards, an equilibrium results, and no part of the body is crushed.

The effect of the internal fluids in resisting the external pressure of the atmosphere may be rendered manifest by applying an exhausting syringe or a cupping-glass to any part of the skin. Such an instrument has no other effect than that of removing the atmospheric pressure from that part of the surface to which it is applied; but when it does this, immediately the skin is distended and sucked, as it were, into the glass, in consequence of the elasticity of the fluids contained in the organs.

252. The various phenomena, which are vulgarly called suction, are merely the effects of atmospheric pressure. If a piece of moist leather be placed in close contact with any heavy body having a smooth surface, such as a stone or a piece of metal, it will adhere to it; and if a cord be attached to the leather, the stone or metal may be raised by it.

This effect arises from the exclusion of the air between the leather and the stone. The weight of the atmosphere presses their surfaces together with a force amounting to 15 lbs. on a square inch of the surface of contact.

253. The power of flies, and other insects, to walk on ceilings, smooth pieces of wood, and other similar surfaces, in doing which the gravity of their bodies appears to have no effect, is explained upon the same principle. Their feet are provided with an apparatus similar exactly to the leather applied to the stone.

254. That the air in the inside of vessels is the force which neutralises the

great pressure of the external air, may be shown by the following experiment:—

A strong glass vessel is provided, open both at top and bottom, and having a diameter of four or five inches. Upon one end is tied a bladder, so as to be completely air-tight (*fig.* 155.). The other end is placed upon the plate of an air-pump, being previously smeared with lard, to make the contact air-tight. The air under the bladder is rarefied by the operation of the pump, and the bladder is subject to a pressure from without, proportional to the difference between the pressure of the external air and the pressure of the rarefied air under the bladder. When the rarefaction has been carried to such an extent that the strength of the bladder is less than this pressure, the bladder bursts with a loud report.

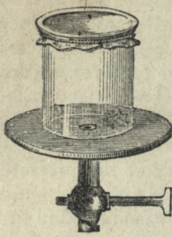


Fig. 155.

255. The great force of the atmospheric pressure is also shown in a striking manner by the apparatus figured below. It consists of two hollow brass hemispheres (*fig.* 156.), with evenly ground edges, which admit of being brought into air-tight contact when smeared with lard. The apparatus when secured upon the plate of an air-pump may be exhausted, so that the space within the hemispheres may be rendered a partial vacuum.

The external air will thus press the two hemispheres together with a force proportional to the difference between the pressure of the external air and the pressure of the rarefied air within. When a sufficient exhaustion has been produced, the stop-cock attached to the lower hemisphere is closed, the apparatus is unscrewed from the pump-plate, and a handle screwed upon the lower hemisphere. It will be found that two of the strongest men will be unable to tear the hemispheres asunder, provided they are of a moderate magnitude, owing to the amount of the pressure with which they are held together. If, for example, the pressure of the rarefied air within is equivalent to a column of two inches of mercury, while the external air has a pressure represented by 30 inches of mercury, there will be a force amounting to 14 lbs. per square inch in the section of the hemispheres.

If the hemisphere have 4 inches diameter, the area of their section will be $12\frac{1}{2}$ square inches, and consequently the force with which they will be pressed together will be

$$12\tfrac{1}{2} \times 14 = 175 \text{ lbs.}$$

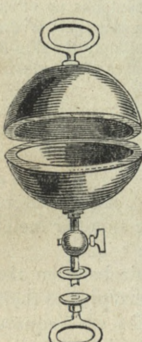


Fig. 156.

This apparatus, called the Magdeburgh hemispheres, derives its name from the place where the inventor of the air-pump, Otto Guericke, first exhibited the experiment, in the year 1654. The section of the hemispheres employed by him measured 113 square inches, and they were held together by a force equal to about three-fourths of a ton.

256. If a solid body, bulk for bulk, be lighter than air, it will ascend in the atmosphere, upon the same principle as that by which a cork rises to the surface in water.

If a hollow vessel of sufficient magnitude could be exhausted by an air-pump, and if it could be constructed with sufficient strength to resist the external pressure of the atmosphere, and at the same time so light that its entire weight would be less than the weight of the air extracted from it by the pump, such a body would necessarily rise in the atmosphere, its weight being less than that of the air it displaces. But these conditions are impracticable: there is no material of which such a body could be constructed, so as to be at the same time sufficiently light and sufficiently strong.

If a fluid could be found lighter, bulk for bulk, than air having the same pressure, then a hollow vessel filled with such a fluid would be subject to no external pressure tending to crush it, and might be lighter, bulk for bulk, than air, and under such circumstances it would ascend in the atmosphere.

The first attempt to realise these conditions was by means of heated air. When air is heated it expands, and, bulk for bulk, becomes lighter than it is at a lower temperature.

If, then, a large bag, composed of paper or silk, or other light material, be filled with heated air, the weight of such a bag, including its contents, might be less than its own bulk of air in the natural state, and it would consequently have a buoyancy proportional to such difference of weight.

257. The application of this principle formed the first successful attempt in aerostation. In the year 1782, the celebrated Montgolfier, residing at Annonai, made a series of experiments which ultimately terminated in the formation of a balloon of the spherical form (*fig.* 157.), containing 23000 cubic feet of heated air, and having such a buoyancy as to be capable of raising a gross weight of 500 lbs. This machine rose in the atmosphere to the height of 6000 feet. In this, and subsequent similar experiments, the air within the balloon was kept heated by a fire which was lighted below it, the balloon having an open mouth at its lowest point, through which the flame of the fire was transmitted.

258. The step from the fire balloon to balloons filled with gas, lighter, bulk for bulk, than the atmosphere, was easy and obvious. The gas denominated hydrogen was no sooner discovered than it was applied to this purpose.

This gas, being about seven times lighter than atmospheric air, has considerable buoyancy; balloons, accordingly, filled with it, would rise to a great height in the atmosphere.

It has been already explained that, as we ascend in the atmosphere, the strata of air have less and less density: a balloon, therefore, containing gas whose pressure balances the lower strata, will, if it be completely filled, have a tendency to burst when it ascends into the rarer strata; for the gas, not having room to expand, will maintain its original elastic force, while the atmospheric pressure, being diminished in the ascent, will cease to balance it. There will therefore be a bursting pressure equivalent to the excess of the atmospheric pressure at the lower strata, over the pressure in the superior strata to which the balloon ascends.

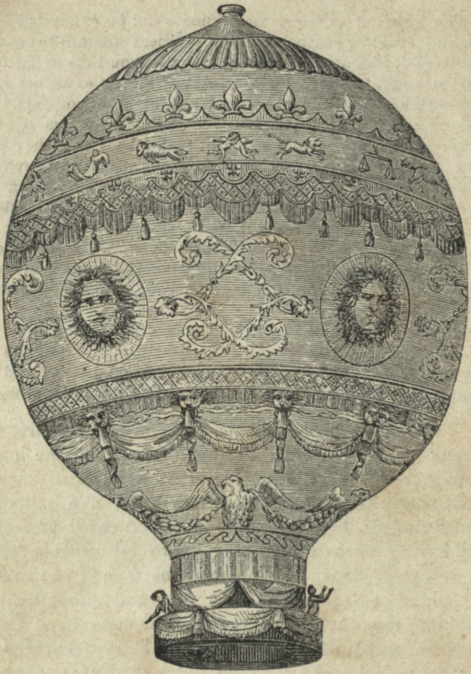


Fig. 157.

259. These effects are prevented practically by inflating, only imperfectly, the balloon at the moment of its ascent. When it rises into the superior strata, the gas accordingly expands, and the balloon becomes comparatively filled, gaining at the same time increased buoyancy by the increased expansion of the gas within it. If it ascend to a still greater height than that at which the inflation becomes complete, it is relieved from the bursting force by means of a safety-valve.

When the aeronaut desires to descend, he is provided with a valve, by which he can discharge a part of the gas, so as to diminish the buoyancy of the balloon; and when he requires to ascend, he is provided with ballast composed of sand-bags, by casting out which he diminishes the weight of the balloon.

Before the introduction of gas-lighting, the process of inflating a balloon consisted in the production of the necessary volume of hydrogen gas by a chemical process. The oil of vitriol being mixed in a small proportion with water, and a quantity of sheet zinc, or zinc filings, or iron filings, being thrown into the liquid, a chemical action takes place, in which the water is

Fig. 158.

decomposed. It is well known that water is a chemical combination of the two gases, oxygen and hydrogen. The presence of the vitriol or sulphuric acid causes the zinc or iron to attract the oxygen of the water, and to form with it an oxide, while the hydrogen, the other component of water, is liberated.

In the process of filling a balloon, a great number of casks or other vessels containing the acid solution and the metal were provided, and the hydrogen, as it was evolved, was conducted to the mouth of the balloon, as shown in *fig.* 158.

Since the general introduction of gas for the purposes of illumination, the inflation of balloons has become much more easy and economical. The gas used for illumination is a species called carburetted hydrogen: it is a little heavier than pure hydrogen, and consequently gives a little less buoyancy than that gas; but it gives sufficient for all the purposes of aerostation.

Wherever gas-works exist, a balloon can be inflated with this gas by merely connecting it by a flexible pipe with a gas main.

260. The first successful experiment made with a hydrogen balloon took place in the Champ de Mars, near Paris, on the 22nd of August, 1783, and on the 1st of December following, Messrs.

Charles and Robert ascended personally, and conducted the experiment without accident.

Fig. 159.

The usual form of the hydrogen balloon, with its car, is shown in *fig.* 159.

261. *Parachutes.* — It has been shown that the resistance of the air soon stops the acceleration of a falling body. Even a cannon ball let fall from a sufficient height would, after a certain time, cease to be accelerated. The major limit of the velocity of the descent would obviously depend upon the weight of the descending body, and the extent of the surface it presented to the air. If the weight be sufficiently small, and the resisting surface sufficiently great, the velocity of the descent may be reduced to a very small amount.

Fig. 160.

Fig. 161.

An expedient called *a parachute*, by which an aeronaut is enabled to let himself fall to the earth with impunity, has been constructed upon this principle, and consists, as shown in *fig.* 160., of an umbrella of vast dimensions, to the handle of which a light basket, to support the aeronaut, is suspended. When the parachute is first disengaged, the umbrella is folded up, as shown in *fig.* 160., and the fall is extremely rapid. But the air, soon entering the folds, makes them expand and take the form shown in *fig.* 161., when the descent is rapidly retarded. This retardation is continually increased as the aeronaut approaches the ground, owing to the increased density of the air.

262. *Kites.*—A kite is sustained in the air by the equilibrium of three forces: 1st, that component of the wind which acts perpendicular to its surface, and which is directed obliquely upwards; 2nd, its own weight, which is directed vertically downwards; and 3rd, the tension of the string, which is directed obliquely downwards. When the kite has assumed such position and height that the first of these three forces is equal, and directly opposed to the resultant of the second and third, the kite will be stationary. If the first be greater than that resultant, the kite will ascend; if less, it will descend.

263. *The Air-gun.*—The air-gun is an instrument by which balls or other missiles are projected by the elastic force of compressed air, instead of the expansive force of gunpowder.

A strong hollow chamber, usually having the form of a metallic sphere, is provided, into which air is driven by means of a condensing syringe. This is screwed upon the gun near the breech, so as to communicate with the interior of the barrel behind the ball, the pipe of communication being governed by a valve or cock, which is connected with the trigger. On drawing the trigger, the valve is opened, and the barrel put in free communication with the condensed air, which, pressing behind the ball, propels it

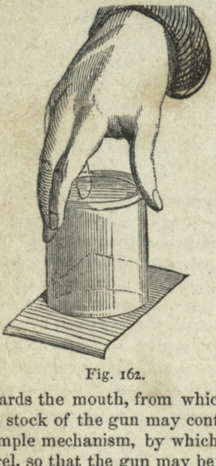


Fig. 162.

Fig. 163.

towards the mouth, from which it is projected with a corresponding force. The stock of the gun may contain a supply of balls, and be furnished with a simple mechanism, by which they may be successively transferred to the barrel, so that the gun may be immediately loaded after each discharge.

264. Let a glass be completely filled with water (*fig.* 162.), and a leaf of paper be so applied to its mouth as to exclude the air, and let the palm of one hand be applied upon it, while the glass is inverted with the other hand. The hand applied to the paper may then be withdrawn; and although the mouth of the glass is presented downwards, the water will not be discharged from it, being supported in it by the pressure of the atmosphere acting on the paper.

Let a glass be plunged in a vessel of water (*fig.* 163.), and, when all the air has been expelled from it, and it is filled with water, let it be raised with its mouth downwards, until the edge of its mouth shall be only a small depth below the surface of the water. It will continue to be completely filled with water, the liquid being sustained in it by the pressure of the atmosphere upon the water in the vessel.

265. *Gasometers.*—This name is somewhat improperly given to large cylindrical reservoirs in which gas is collected, in gas-works, for general distribution. These reservoirs act upon the principle here explained; they consist, as shown in *fig.* 164., of a large cylindrical reservoir suspended with

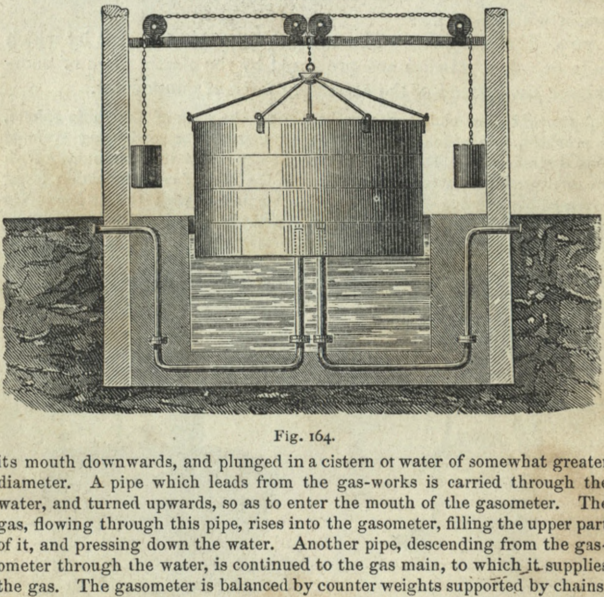


Fig. 164.

its mouth downwards, and plunged in a cistern of water of somewhat greater diameter. A pipe which leads from the gas-works is carried through the water, and turned upwards, so as to enter the mouth of the gasometer. The gas, flowing through this pipe, rises into the gasometer, filling the upper part of it, and pressing down the water. Another pipe, descending from the gasometer through the water, is continued to the gas main, to which it supplies the gas. The gasometer is balanced by counter weights supported by chains, which pass over pulleys, and just such a preponderance is allowed to it as is sufficient to give the gas contained in it, the compression necessary to drive it through the pipes to the remotest part of the district to be illuminated.

266. The diving bell is constructed upon the same principle as the gasometer. It is let into the water with the mouth downwards, the divers being seated in it and sunk by weights. The air con-

tained in it prevents the water from rising, and fresh air is supplied to the divers by pipes carried down, through which the fresh air is forced.

267. Bellows derive their efficacy from the *elasticity and pressure of the atmosphere.*

When the boards A B (*fig.* 165.) of the bellows are separated, the inner chamber C is enlarged, and the air is forced in by the external pressure through the aperture D, governed by the leather valve or clack. The boards being then pressed together, and the escape of the air being stopped by the closed valve, it is compressed until it acquires an elasticity greater than the atmospheric pressure, and is forced out.

Fig. 165.

Bellows on a large scale are constructed with an intermediate board B (*fig.* 166.), so as to consist of two chambers, F and C, and to produce a continued instead of an intermitting blast. This is nothing more than a double bellows, one, C, forcing air into the chamber of the other, F, and the second being urged by an uninterrupted pressure, produced usually by a weight suspended from the upper board.

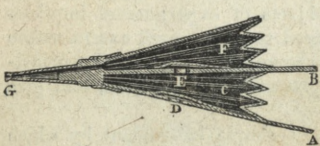


Fig. 166.

268. The effect of a vent-peg is explained by the atmospheric pressure.

So long as the peg stops the hole in the top of the barrel, the pressure of the atmosphere will prevent the flow of the liquid from the cock, but when the vent-peg is withdrawn, the air being admitted presses on the liquid above with as much force as the pressure of the liquid issuing from the cock, and these two pressures being in equilibrium, the liquid flows out, in virtue of the weight of the column in the barrel above the level of the cock.

Ink-bottles are sometimes so constructed as to prevent the inconvenience of the ink thickening and drying. Such a bottle, represented in *fig.* 167., is a close glass vessel, from the bottom of which a short tube proceeds, the depth of which is sufficient for the immersion of a pen. When ink is poured in at C, the bottle, being placed in an inclined position, is gradually filled to A. If the bottle be now placed in the position represented in the figure, the chamber A being filled with the liquid, the air will be excluded from it; and the pressure, tending to force the ink upwards in the short tube C, will be equal to the weight of the column of ink, the height of which is equal to the depth of the ink in the bottle A, and the bore of which is equal to the section of the tube C. The ink will be pre-

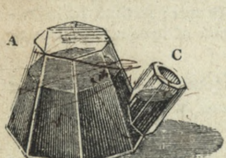


Fig. 167.

vented from rising in the tube C by the atmospheric pressure, which is much greater than the pressure of the column of liquid in the bottle. As the ink in the short tube C is consumed by use, its surface will gradually fall, a small bubble of air will then insinuate itself, and will rise to the top of the bottle A, where it will exert an elastic pressure, which will cause the surface of the ink in C to rise a little higher; and this effect will be continually repeated, until all the ink in the bottle has been used.

Bird-cage fountains are constructed on the same principle.

The peculiar gurgling noise produced in decanting wine arises from the pressure of the atmosphere forcing air into the interior of the bottle to replace the liquid which escapes.

269. The effects, infinitely various, produced by the atmosphere on bodies, whether organised or unorganised, cannot be made fully manifest unless we are enabled to exhibit the same objects under other atmospheric conditions, such as when exposed to an atmosphere much more rare and much more condensed. Instruments for experimental investigation have been accordingly contrived, by which the air surrounding objects of experimental inquiries can be either rarefied or condensed to any desired extent within practical limits. We shall now proceed to explain the principal instruments by which these processes are exhibited, and give some examples of their use.

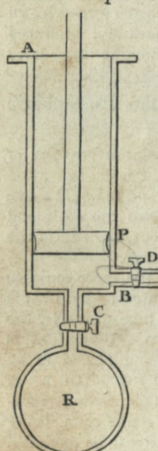


Fig. 168.

270. The most simple instrument by which air can be withdrawn from any vessel, is the *exhausting syringe*, the principle of which will be understood from *fig.* 168.

Let the stop-cock C be opened and D closed, the piston P being then drawn up, the air in R will expand so as to fill the cylinder A B. Let the cock C be then closed and D opened, and the air in the piston again driven down. The air in the cylinder A B will then be driven out through the cock D. Let the cock D be then closed and C opened, and let the process be repeated. By each upstroke of the piston a quantity of air will escape from R by expansion, and by each down-stroke this quantity will be expelled through D by compression.

In the practical form of the syringes the cocks D and C are replaced by valves, C being a valve opening upwards, and D one opening outwards; so that the instrument acts without the operation of opening and closing the cocks.

271. The same arrangement, only reversing the operation of the valves, will produce a *condensing syringe*.

Let the cock C be closed, and D opened, and let the piston be drawn to the top of the cylinder. Air entering through D will fill the cylinder. Let the cock D be then closed, and C opened, and let the piston be driven down, the air in the cylinder will then be forced through C into R. Let the cock C be then closed, and D opened, and the operation repeated, and the same result will ensue. In this way, with each stroke of the piston, a cylinder full of air will be forced into R, which will thus contain condensed or compressed air. In the practical form of the condensing syringe, D is a valve opening inwards, and C, one opening downwards.

272. The *air-gun*, already described, is charged by the operation of such a syringe.

273. An *air-pump* is an instrument used for philosophical purposes, by means of which the air can be withdrawn from any vessel in which an experiment is desired to be made. The vessel from which the air is withdrawn is generally a glass bowl, the mouth of which rests in air-tight contact upon a circular plate, in the centre of which is a hole communicating with exhausting syringes, by which the air is withdrawn. The most common form of air-pump, shown in *fig.* 169., consists of two exhausting syringes worked by

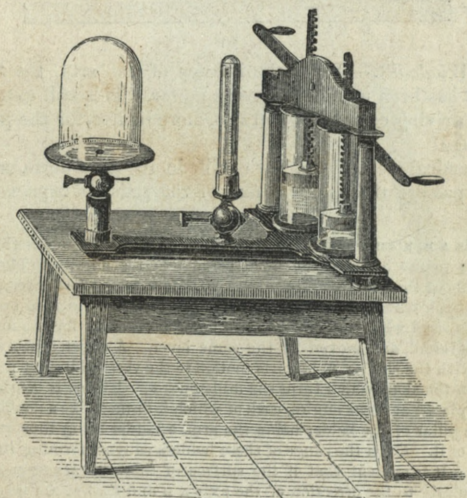


Fig. 169.

racks and pinions, communicating, as shown in *fig.* 170., with the air-pump plate by a rectangular tube supplied with cocks, by which the communication between the receiver and the syringe can be opened and closed at pleasure. A mercurial gauge, upon the principle of the common barometer, is usually attached to such an instrument, by which the degree of rarefaction produced by the syringes can be measured.

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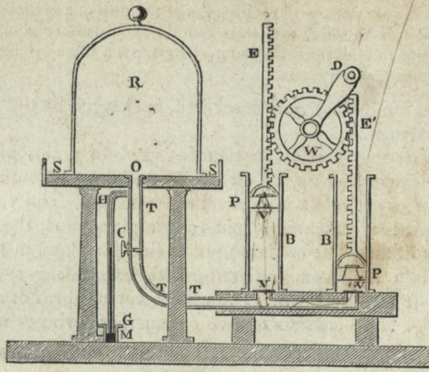

Fig. 170.

274. *Windmills.* — Since the infancy of the arts, the force of the wind has been used as a moving power. It is still extensively used for driving corn mills, and also, more or less, for the purposes of drainage.

The vertical section of a corn mill, in its usual form, made by a plane passing through the axis of the sails, is represented in *fig.* 171.

The axis A B, upon which the sails revolve, is inclined at an angle of 10 or 15 degrees to the horizon, the wind being found generally to blow downwards at about that angle. The entire structure is supported on a vertical axis H G, upon which it can be turned by a long lever K, so as to present the sails to the wind whatever be its direction. The ladder for mounting into the mill is raised, and moved by the same lever. A crown wheel D, which revolves with the shaft A B, imparts motion to the vertical basket E, which is fixed upon the shaft which turns the millstones F. The sails consist of four arms A C, placed at right angles, each of which is formed like a double ladder, the centre pillar of the ladder being the arm, a ladder being thus ranged on each side of it. Upon the rungs of these ladders canvass forming the sails is stretched. It is evident that if the surface of this canvass were presented perpendicularly to the direction of the axis A B and that of the wind, no revolution would be produced, the whole force of the wind having no other effect than to strain the arms of the mill; but by inclining the canvass at a proper angle to the direction of the wind, the force of the latter, as in the case of the sails of vessels, is resolved into components, one of which will be directed at right angles to the arm of the mill.

275. A siphon is an apparatus by which a liquid can be decanted from one vessel to another without inverting or otherwise disturbing the position of the vessel from which the liquid is removed.

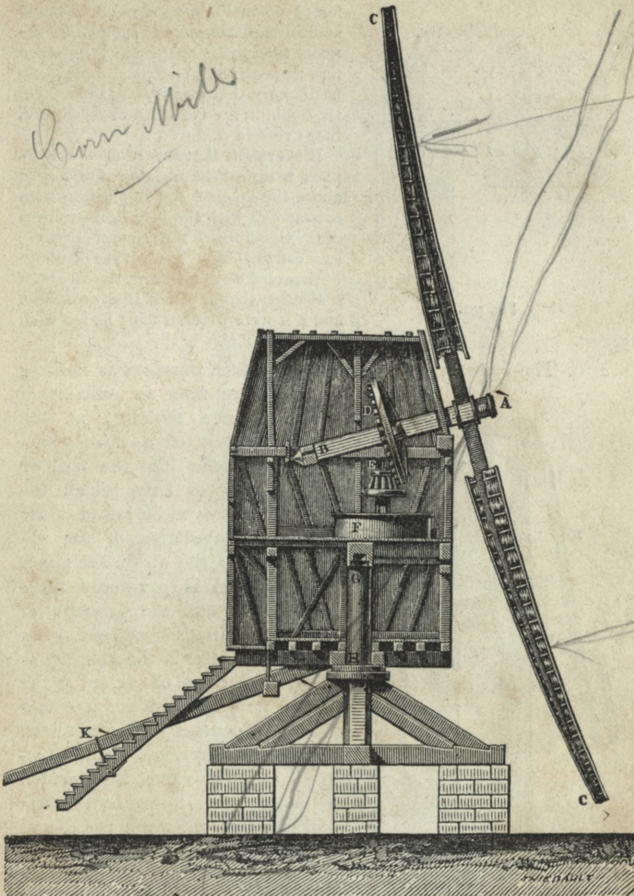

Fig. 171.

Let D, *fig.* 172., be a vessel containing a liquid, and let B be the height over which it is necessary to conduct the liquid, so as to transfer it to the vessel F G. Let A B C be a bent tube open at both ends, and let the leg B A be immersed in the liquid which it is required to transfer, and let the leg B C be directed into the vessel into which the liquid is to be removed. Let the air which fills the tube A B C be drawn from it by the mouth placed at C, or by an exhausting syringe. The liquid in the vessel D will then be

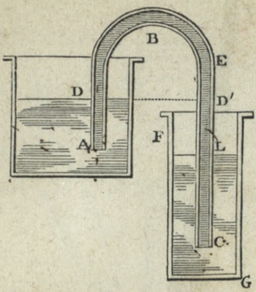

Fig. 172.

forced up in the pipe A B by the pressure of the atmosphere, and will fill the under tube to the mouth C. It will then flow through the siphon, and continue to be discharged at C so long as the level of the liquid in the vessel D is above its level in the vessel F G.

It is evident that the bend of the siphon B cannot be at a greater height above the level of the liquid in D than corresponds with the height of a column of the liquid which the atmospheric pressure can support. Thus, if the liquid to be decanted were mercury, the height of B above D should be less than 30 inches; and if it were water, it must be less than 34 feet.

276. The *common pump* used for domestic purposes is nothing more than an exhausting syringe mounted at the summit of a pipe, which descends into the well or reservoir from which the water is to be raised. By the operation of the syringe, the air in the pump barrel is gradually rarefied, and the pressure of the atmosphere, acting on the water in the well, forces a column of water up the pump barrel till it comes in contact with the piston of the syringe. In this piston a valve is provided opening upwards, through which the water passes and is elevated by the up-stroke of the piston and discharged at a pipe placed in any convenient position.

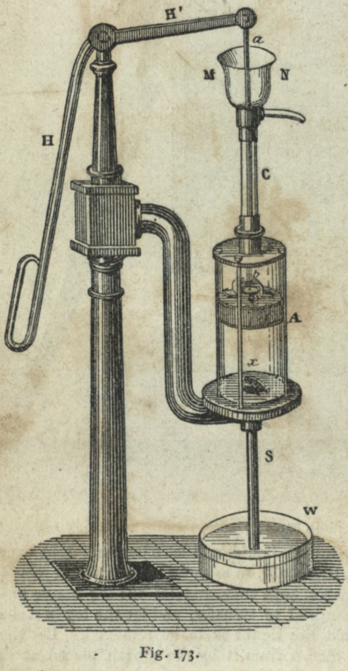

Fig. 173.

Fig. 173. represents the common form of pump used for the purposes of illustration. H H, is the handle or break; A the barrel in which the piston plays and which is, in fact, an exhausting syringe; S the pipe which descends into the well or reservoir; C the pipe leading to the point of discharge.

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277. A *force pump* consists of an exhausting syringe supplied with a piston having no valve in it. The water is drawn from the well upon the same principle as in the common pump just described, and when the pump barrel under the piston is filled with it, the piston in descending presses upon the water, which is prevented from returning to the well by a valve under it, which opens upwards, and is forced through another valve, which opens at the side, into a force pipe which leads to a receiver called an air vessel. When the water is forced into this receiver, the air, being compressed above it, reacts upon it, and forces it in a condensed stream through a pipe provided for the purpose.

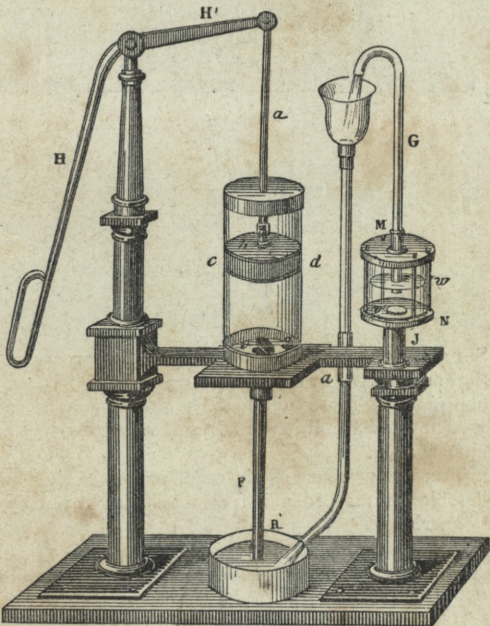


Fig. 174.

An illustrative model of the force pump is shown in *fig.* 174., where *c d* is the pump barrel; M N the air vessel, and G the force pipe, up which the water is driven by the reaction of the air.

278. The fire-engine is a double forcing pump, each barrel of which acts upon the principle here explained. A section of such an engine in its usual form is represented in *fig.* 175. The operation of it will be readily understood by what has been already explained.

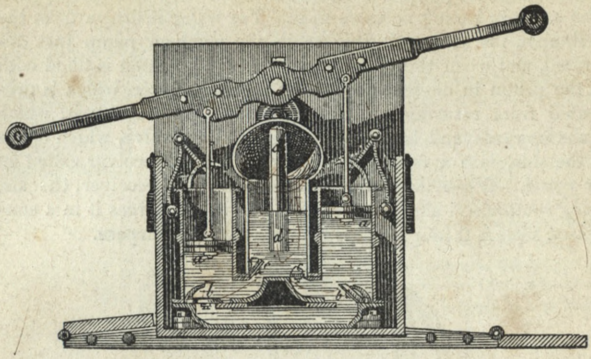


Fig. 175.

CHAP. XI.

SOUND.

279. **Sound** is the sensation produced in the organs of hearing when they are affected by undulations transmitted to them through the atmosphere. These undulations are subject to an infinite variety of physical conditions, and each variety is followed by a different sensation.

280. That the presence of air or other conducting medium is indispensable for the production of sound, is proved by the following experiment.

Let a small apparatus (*fig.* 176.) called an alarum, consisting of a bell *a*, which is struck by a hammer *b*, moved by clockwork, be placed under the receiver of an air-pump, through the top of which a rod slides, air-tight, the end of the rod being connected with a detent which governs the motion of the clockwork connected with the hammer. This rod can, by a handle placed outside the receiver, be made to disengage the detent, so as to make the bell ring whenever it is desired.

This arrangement being made, and the alarum being placed within the receiver, upon a soft cushion of wool *e*, so as to prevent the vibration from being communicated to the pump-plate, let the receiver be exhausted in the usual way. When the air has been withdrawn, let the bell be made to ring by means of the sliding-rod. No sound will be heard, although the percussion of the tongue upon the bell, and the vibration of the bell itself, are

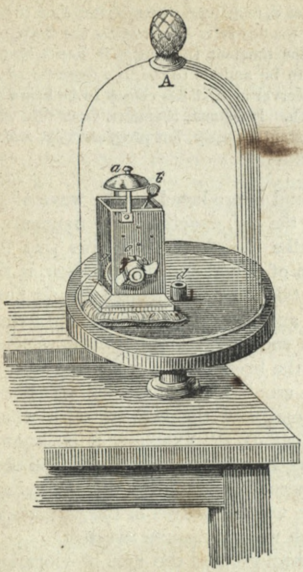


Fig. 176.

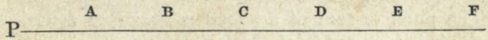
visible. Now if a little air be admitted into the receiver, a faint sound will begin to be heard, and this sound will become gradually louder in proportion as the air is gradually readmitted.

In this case the vibrations which directly act upon the ear are not those of the air contained in the receiver. These latter act upon the receiver itself and the pump-plate, producing in them sympathetic vibration ; and those vibrations impart vibrations to the external air which are transmitted to the ear.

If in the preceding experiment a cushion had not been interposed between the alarum and the pump-plate, the sound of the bell would have been audible, notwithstanding the absence of air from the receiver. The vibration in this case would have been propagated, first from the bell to the pump-plate and to the bodies in contact with it, and thence to the external air.

281. Since the propagation of undulations through the atmosphere is progressive, an interval of time, more or less, must elapse between the vibration of the sounding body and the perception of the sound by a hearer, and such interval will be proportionate to the distance of the hearer from the sounding body, and to the velocity with which sound is propagated through the intervening medium. This progressive propagation of sound can be directly proved by experiment.

Let a series of observers, A, B, C, D, &c., be placed in a line, at distances of about 1000 feet asunder, and let a pistol be discharged at P, about 1000 feet from the first observer.



This observer will see the flash of the pistol about one second before he hears the report. The observer B will hear the report one second after it has been heard by A, and about two seconds after he sees the flash. In the same manner, the third observer at C will hear the report one second after it has been heard by the observer at B, and two seconds after it has been heard by the observer at A, and three seconds after he perceives the flash. In the same way, the fourth observer at D will hear the report one second later than it was heard by the third observer at C, and three seconds later than it was heard by the observer at A, and four seconds after he perceives the flash.

Now it must be observed, that at the moment the report is heard by the second observer at B, it has ceased to be audible to the first observer at A; and when it is heard by the third observer at C, it has ceased to be heard by the second observer at B, and so forth. It follows, therefore, from this, that sound passes through the air, not instantaneously, but progressively, and at a uniform rate.

282. As the sensation of sound is produced by the wave of air impinging on the tympanum of the ear, exactly as the momentum of a wave of the sea would strike the shore, it follows that the interval between the production of sound and its sensation, is the time which such a wave would take to pass through the air from the sounding body to the ear; and since these waves are propagated through the air in regular succession, one following another without overlaying each other, the breadth of a wave may always be determined if we take the number of vibrations which the sounding body makes in a second, and the velocity with which the sound passes through the air. If, for example, it be known that in a second a musical string makes 500 vibrations, and that the sound of this string takes a second to reach the ear of a person at a distance of 1000 feet, there are 500 waves in the distance of 1000 feet, and consequently each wave measures two feet.

The velocity of the sound, therefore, and the rate of vibration, are always sufficient data by which the length of a sonorous wave can be computed.

283. It has not been ascertained, with any clearness or certainty, by what physical distinctions vibrations which produce common sounds or noises are distinguished from such as produce musical sounds. It is nevertheless certain, that all vibrations, in proportion as they are regular, uniform, and equal, produce sounds proportionably more agreeable and musical.

Sounds are distinguished from each other by their *pitch* or *tone*, in virtue of which they are high or low; by their *intensity*, in virtue of which they are loud or soft; and by a property expressed in French by the word *timbre*, which we shall here adopt in the absence of any English equivalent.

284. The pitch or tone of a sound is grave or acute. In the former case it is low, and in the latter high, in the musical scale.

The more rapid the vibrations are, the more acute will be the sound. A bass note is produced by vibrations much less rapid than a note in the treble.

All vibrations which are performed at the same rate produce waves of equal length and sounds of the same pitch.

285. The intensity of a sound, or its degree of loudness, depends on the force with which the vibrations of the sounding body are made.

286. The timbre of a sound is not easily explained, and still less easily can the physical conditions on which it depends be ascertained. If we hear the same musical note produced with the same degree of loudness in an adjacent room successively upon a flute, a clarionet, and a hautboy, we shall, without the least hesitation, distinguish the one instrument from the other. Now this distinction is made by observing some peculiarity in the notes produced, yet the notes shall be the same, and be produced with equal loudness.

287. It is manifest from the absence of all confusion in the effects of music, at whatever distance it may be heard, that in the same medium all sounds have the same velocity. If the different notes simultaneously produced by the various instruments of an orchestra moved with different velocities through the air, they would be heard by a distant auditor at different moments, the consequence of which would be, that a musical performance would, to the auditors, save those in immediate proximity with the performers, produce the most intolerable confusion and cacophony; for different notes produced simultaneously, and which, when heard together, form harmony, would at a distance be heard in succession; and sounds produced in succession would be heard as if produced together, according to the different velocities with which each note would pass through the air.

288. The velocity of sound varies with the elasticity of the medium by which it is propagated. Its velocity, therefore, through the air will vary, more or less, with the barometer and thermometer.

The experimental methods which have been adopted to ascertain the velocity of sound, are similar in principle to those which have been briefly noticed by way of illustration. The most extensive and accurate series of experiments which have been made with this object, were those made at Paris by the Board of Longitude in the year 1822. The sounding bodies used on this occasion were pieces of artillery charged with from two to three pounds of powder, which were placed at Villejuif and Montlhéry. The experiments were made at midnight, in order that the flash might be more easily and accurately noticed. They were conducted by MM. Prony, Arago, Mathieu, Humboldt, Gay Lussac, and Bouvard. The result of these experiments was, that when the barometer was at 29·8 inches, and the thermometer at 61°, the velocity of sound was 1118·4 feet per second.

According to the theory of Laplace, the velocity of sound increases at the rate of 1·11 feet per second for every degree in the rise, and decreases at the same rate for each degree in the fall of the thermometer. Hence it appears that the velocity of sound at 32° is 1086·2 feet per second. For all practical purposes, it is sufficiently exact to take 1120 feet as the velocity of sound at 62°, and allow thirteen inches for every variation of a degree in temperature.

289. The production of sound is in many cases attended with the evolution of light, as, for example, in fire-arms and explosions generally, and in the case of atmospheric electricity. In these cases, by noting the interval between the flash and the report, and multiplying the number of seconds in each interval by the number of feet per second in the velocity of sound, the distance can be ascertained with great precision. Thus, if a flash of lightning be seen ten seconds before the thunder which attends it is heard, and the atmosphere be in such condition that the velocity of sound is 1120 feet per second, it is evident that the distance of the cloud in which the electricity is evolved must be 11200 feet.

290. The same sounding body will produce a louder or lower sound, according as the density of the air which surrounds it is increased or diminished. In the experiment already explained, in which the alarum was placed under an exhausted receiver, the sound increased in loudness as more and more air was admitted within the receiver. If the alarum had been placed under a condenser, and highly compressed air collected round it, the sound would be still further increased.

When persons descend to any considerable depth in a diving-bell, the atmosphere around them is compressed by the weight of the column of water above them. In such circumstances a whisper is almost as loud as the common voice in the open air, and when one speaks with the ordinary force it produces an effect so loud as to be painful.

On the summit of lofty mountains, where the barometric column falls to one-half its usual elevation, and where therefore the air is highly rarefied, sounds are greatly diminished in intensity. Persons who ascend in balloons find it necessary to speak with much greater exertion, and, as would be said, louder, in order to render themselves audible. When Saussure ascended Mont Blanc, he found that the report of a pistol was not louder than a common cracker.

291. Violent winds and other atmospheric agitations affect the transmission of sound. When a strong wind blows from the hearer towards the sounding body, a sound often ceases to be heard which would be distinctly audible in a calm. A tranquil and frosty atmosphere placed over a smooth and level surface is favourable to the transmission of sound. Lieutenant Forster held a conversation with a person on the opposite side of the harbour of

Port Bowen, in the third polar expedition of Sir Edward Parry, the distance between the speakers being more than a mile.

It is said that the sound of the cannon at the battle of Waterloo was heard at Dover, and that the cannon in naval engagements in the Channel have been heard in the centre of England.

292. Liquids are also capable of propagating sound. Divers can render themselves audible at the surface of the water; and stones or other objects struck together at the bottom produce a sound audible at the surface.

It appears from the experiments of M. Colladon, made at Geneva, that sounds are transmitted through water to great distances with greater force than through air. A blow struck under the water of the Lake of Geneva was distinctly heard across the whole breadth of the lake, a distance of nine miles.

Solid bodies, such as walls or buildings interposed between the sounding body and the hearer, diminish the loudness of the sound, but do not obstruct it when the sound is made in air; but it appears from the experiments of M. Colladon, that the interposition of such obstacles almost destroys the transmission of sound in water.

293. Solids which possess elasticity have likewise the power of propagating sound. If the end of a beam composed of any solid possessing elasticity be lightly scratched or rubbed, the sound will be distinct to an ear placed at the other end, although the same sound would not be audible to the ear of the person who produces it, and who is contiguous to the place of its origin.

The earth itself conducts sound, so as to render it sensible to the ear when the air fails to do so. It is well known, that the approach of a troop of horse can be heard at a distance by putting the ear to the ground. In volcanic countries, it is said that the rumbling noise which is usually the prognostic of an eruption is first heard by the beasts of the field, because their ears are generally near the ground, and they then by their agitation and alarm give warning to the inhabitants of the approaching catastrophe. Savage tribes practise this method of ascertaining the approach of persons from a great distance.

294. The velocity with which sound is transmitted through the air varies with its elasticity; and where different strata are rendered differently elastic by the unequal radiation of heat, the agency of electricity, or other causes, the transmission of sound will be irregular. In passing from stratum to stratum differing in elasticity, the speed with which sound is propagated is not only varied, but the force of the intensity of the undulations is diminished by the combined effects of reflection and interference,

so that the sound, on reaching the ear, after passing through such varying media, is often very much diminished.

The fact, that distant sounds are more distinctly heard by night than by day, may be in part accounted for by this circumstance, the strata of the atmosphere being during the day exposed to vicissitudes of temperature more varying than during the night.

295. The solids composing the body of an animal are capable of transmitting the sonorous undulations to the organ of hearing, even though the air surrounding that organ be excluded from communicating with the origin of the sound.

Chladni showed that two persons stopping their ears could converse with each other by holding the same stick between their teeth, or by resting their teeth upon the same solid. The same effect was produced when the stick was pressed against the breast or the throat, and other parts of the body.

If a person speak, directing his mouth into a vessel composed of any vibratory substance, such as glass or porcelain, the other stopping his ears, and touching such vessel with a stick held between his teeth, he will hear the words spoken.

The same effect will take place with vessels composed of metal or wood.

If two persons hold between their teeth the same thread, stopping their ears, they will hear each other speak, provided the thread be stretched tight.

296. Of the various forms of apparatus which have been contrived for the production of musical sounds, with a view to the

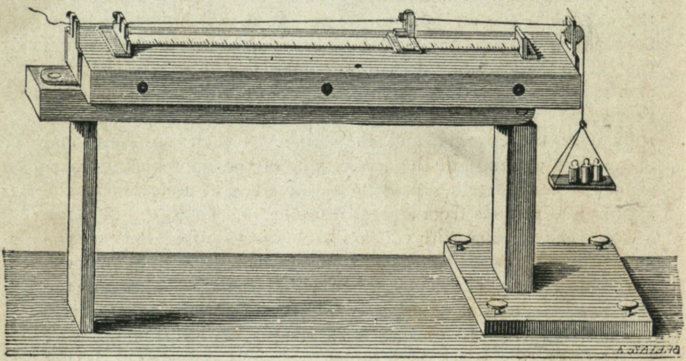


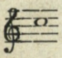
Fig. 177.

experimental illustration of their theory, that which is best adapted for this purpose, is called a *monochord* or *sonometer*.

(*Fig.* 177.) consists of a string of catgut or wire attached to a fixed point carried over a pulley, and stretched by a known weight. Under the string is a hollow box or sounding-board, to the frame of which the pulley is attached. The string rests upon two bridges, one of which is fixed, and the other can be moved with a sliding motion to and fro, so as to vary at pleasure the length of the part of the string included between the two bridges.

A divided scale is placed under them, so that the length of the vibrating part of the string may be regulated at pleasure. By varying the weight, the tension of the string may be increased or diminished in any desired proportion. This may be accomplished with facility by circular weights which are provided for the purpose, and which may be slipped upon the stem of the weight. By means of this apparatus, the relation between the various notes of the musical scale and the rate of vibration by which they are respectively produced have been ascertained.

297. The rate of vibration of a string such as that of the monochord is inversely as its length, other things being the same. Thus, if its length be halved, its rate of vibration is doubled; if its length be diminished or increased in a threefold proportion, its rate of vibration will be increased or diminished in the same proportion; and so forth.

Let the bridges be placed at a distance from each other as great as the apparatus admits, and let the weight which stretches the string be so adjusted, that the note produced by vibrating the string shall correspond with any proposed note of the musical scale; such, for example, as , the low C of the treble clef. This being done, let the movable bridge be moved towards the fixed bridge, continually sounding the string until it produces the octave above the note first sounded, that is, until it produces the middle C  of the treble.

If the length of the string be now ascertained by reference to the scale of the monochord, it will be found to be precisely one-half its original length.

298. Hence it follows, that the same string will sound an octave higher if the length is halved. But the rate of vibration will be doubled when the length of the string is halved. Hence it follows, that two sounds, one of which is an octave higher than the other, will be produced by vibrations, the rate of which will be in the proportion of 2 to 1; and, consequently, the length of the undulation producing the lower note will be double that of the undulation producing the higher note.

By like experiments it is shown that the more frequent the coincident vibrations are, the more perfect is the harmony, and the less frequent they are, the more discordant are the notes.

CHAP. XII.

OPTICS.

299. Light is the physical agent by which the material world is rendered manifest to the sense of sight. *Luminaries* are bodies which are original sources of light, such as a lamp or candle, red-hot metal, the electric spark, lightning, and so forth. *Non luminous* bodies are rendered visible by receiving light from luminous ones, and reflecting such light to the eye.

300. *Transparent bodies* are those through which light passes. *Opaque bodies* are impervious to light. Glass, air, and water, are transparent; metals, stone, and wood are opaque.

301. When bodies are imperfectly transparent, light passes through them in a confused manner, so that objects cannot be seen through them. Ground glass, oil paper, horn, foggy air, clouds, tortoise shell, &c., are examples of imperfectly transparent bodies.

302. Light proceeds in straight lines when not deflected from its natural course, and these straight lines are called *rays of light.*

303. A point from which numerous rays of light diverge, is called a *luminous point* or *focus.*

304. Any collection of rays diverging from a point, or proceeding parallel to each other, is called a *pencil of rays.* The point from which they diverge or towards which they converge, is called the *focus of the pencil.*

305. It is owing to the rectilinear propagation of light, that the shadows of bodies correspond more or less with their profiles. Thus the shadow of a globe is a circle (*fig.* 178.).

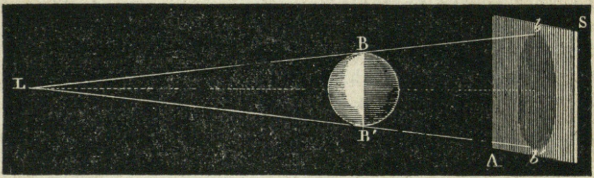


Fig. 178.

306. When a luminous body has a certain magnitude, each point of it casts a separate shadow, and hence arises an indistinctness in the edge of the general shadow, called a *penumbra.*

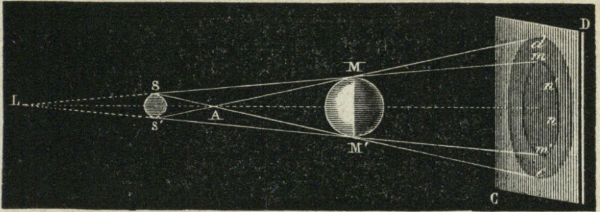


Fig. 179.

In *fig.* 179, ss′, represents a luminous body. The shadow produced by the point s is limited above at *m*, and below at *c*; while the shadow produced by s′ is limited above at *d*, and below at *m*′. Thus the space *m m*′ is a complete shadow, while the space above *m* and below *m*′ is partially illuminated.

307. The intensity of the light which proceeds from a luminous point, decreases in the same proportion as the square of the distance from the point increases.

This is evident if it be considered that in receding from the point the luminous rays separate more and more from each other, so that a less number of them will fall upon a given extent of surface. Thus the number of rays which will fall upon a square inch at a certain distance will be four times the number that would fall upon a square inch at twice that distance, nine times the number at three times that distance, and so on.

308. When rays of light fall upon a polished surface which is not transparent, they will be reflected from it, and the reflected rays in such cases will be inclined to the surface, at the same angle as were the rays incident upon it. It is upon this property that the effect of mirrors and other plane reflectors depends.

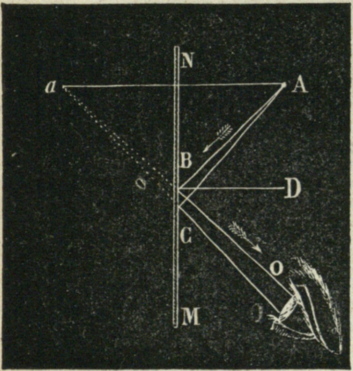


Fig. 180.

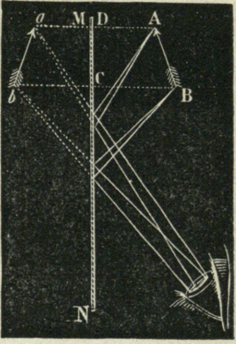


Fig. 181.

Let M N (*fig.* 180.) represent a plane reflector, such as a common looking-glass; and let A be any point upon an object placed before it at the distance A N. The rays which diverge from A, and strike upon the mirror at B C, will be reflected from B C towards O, as indicated by the arrow, exactly as if they had proceeded from a point *a* as far behind the mirror as A is before it, and the impression produced upon the eye at O will consequently be the same as if the point A were really at *a*.

In the same manner, if an object A B (*fig.* 181.) be placed before a plane reflector M N, the rays which diverge from the several points of it will be reflected by M N towards the eye of the observer, as if they came from the same body placed at *a b* as far behind the mirror as the real object A B is before it.

309. In general, therefore, when objects are placed at any distance before a mirror, they will appear, when seen in the mirror, as if they were at an equal distance behind it. When a person looks at himself in a glass (*fig.* 182.), he will see his own image for this reason, as if it were standing at an equal distance behind the glass.

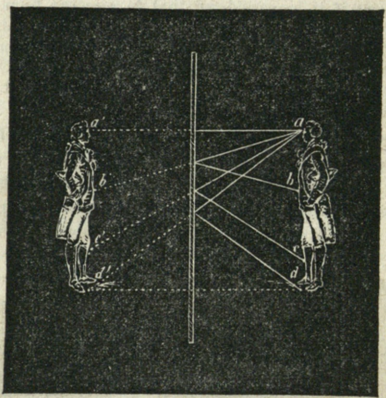


Fig. 182.

310. If an object be placed before a convex spherical mirror, its image will be formed behind the mirror, but not at an equal distance, as is the case in plane mirrors. The distance of the image behind the mirror is always less than the distance of the object before it, and the magnitude is also less.

Thus if L M (*fig.* 183.) be an object placed in front of a convex mirror A C, the image of the object will be formed at *l m*, at a distance from the mirror less than half the radius O E, and the image will be less than the object.

311. If, on the contrary, an object L M (*fig.* 184.) be placed before a concave mirror at a distance from it less than half the radius O B, its image

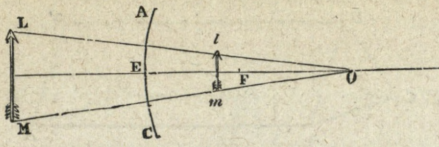


Fig. 183.

l m will be formed behind the mirror at a greater distance from it than the object, and will be greater in magnitude than the object.

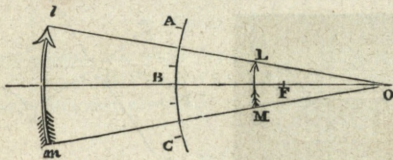


Fig. 184.

312. When a ray of light passes from one transparent medium into another, it is generally deflected from its course, and this deflection is called refraction.

Thus, if C be an object, such as a piece of money (*fig.* 185.), placed at the bottom of a vessel of water, the ray of light proceeding from C to the surface of the water at B, and thence passing into the air, is bent out of its course, and instead of continuing to proceed in its direction C B, will be deflected in the direction B E; so that an observer at E will see the object. not at C, but in the continuation of the line E B. If the water were in this case discharged from the vessel, the object C, which was visible while the water was present, would cease to be visible to the eye at E, being intercepted by the side of the vessel.

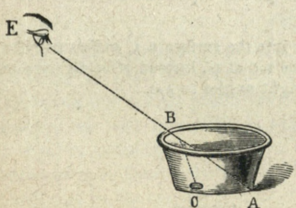


Fig. 185.

313. If a ray of light pass successively through two or more surfaces of transparent media, it may suffer a succession of refractions, by which it will be turned more or less out of its original course.

314. A *prism* is a triangular piece of glass represented in outline in *fig.* 186., and in perspective in *fig.* 187.

315. If A B C (*fig.* 188.) represent a transverse section of such a prism, a ray of light P Q, passing through it will be twice refracted, first, in entering, and, secondly, in leaving it. On entering the prism the ray P O is deflected in the direction O O′, and, in issuing from it, is again deflected in the direction O′ R, so that the ray, which originally had the direction P O, will, by the double action of the prism, be deflected into the direction O′ R.

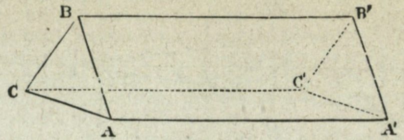


Fig. 186.

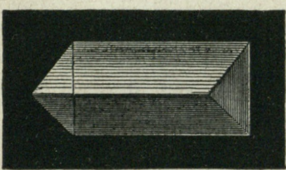


Fig. 187.

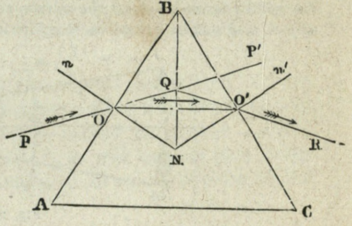


Fig. 188.

316. Certain cases occur, however, in which the ray, after passing through the prism and encountering its second surface, instead of being refracted, is reflected. This happens, for example, in the case of a rectangular prism represented in section at A B C (*fig.* 189.)

The ray P O passing perpendicularly into the surface B A, suffers no refraction; but when it encounters the surface B C at O′, instead of being refracted, it is reflected in the direction O′ R, at right angles to A C.

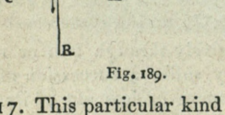


Fig. 189.

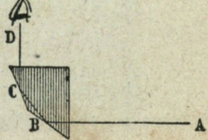


Fig. 190.

317. This particular kind of reflection, from its exceeding brilliancy, is called *total reflection*, no sensible quantity of light being lost. In *fig.* 190. a case is illustrated in which two such reflections take place. The ray A B being first reflected at B, and secondly at C, issues from the prism towards the eye at D.

318. A *lens* is a circular piece of glass usually of small thickness, the surfaces of which are either convex or concave. If both surfaces be convex, as in *fig.* 191., it is called a *double convex* lens; and if both surfaces be concave, as in *fig.* 192., it is called a *double*

concave lens. If one surface be convex, and the other concave, it is called a *concavo-convex* lens, when the concavity is greater than the

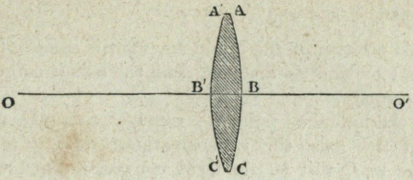


Fig. 191.

convexity, and a *meniscus* when the convexity is greater than the concavity. If one surface of the lens be plane, it is called *plano-convex* or *plano-concave*, according as the other surface is convex or concave.

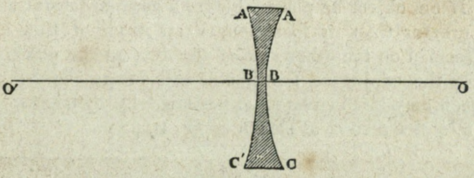


Fig. 192.

319. The practical effect of a meniscus or plano-convex lens, is the same as that of a double convex, and the practical effect of a concavo-convex or plano-concave is the same as that of a double concave, so that generally it will be enough to explain the effects of double convex and double concave lenses. It is true that lenses of the other forms have peculiar properties, which, however, it will not be necessary to notice here.

320. The effect of a double convex lens is to diminish the divergency, or increase the convergency of rays.

If a luminous point be placed at a certain small distance from such a lens,

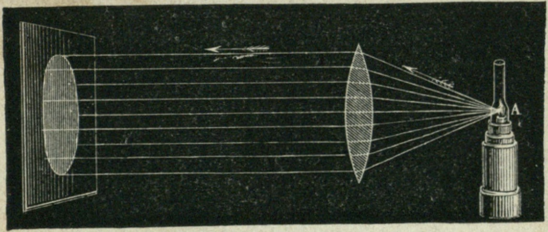


Fig. 193.

the rays issuing from it, after passing through the lens, will be less divergent. If the point be removed to a gradually increasing distance from the lens, a certain position will be found, at which the rays, after passing through the lens, will be parallel, as shown in *fig.* 193.

321. This position of the luminous point is called the *principal focus* of the lens, and its distance from the lens is called the *principal focal distance*.

322. If the luminous point be removed to a still greater distance from the lens, the rays diverging from it, after passing through the lens, will be rendered convergent, and will, in fact, converge to a point at a certain distance on the other side of the lens. The luminous point is, in this case, called the *focus of incident rays*, and the point to which the rays after passing through the lens converge, is called the *conjugate focus* or focus of refracted rays.

323. If an object be placed before a convex lens at a distance from it greater than its focal length, an image of such an object will be formed on the other side of the lens at the point just described as the conjugate focus, and this image will be inverted. This effect may be illustrated experimentally by means of candle A, lens B, and screen C, as shown in *fig.* 194.

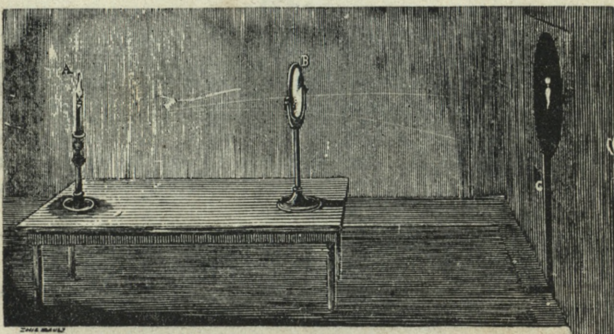


Fig. 194.

324. Solar light is compound, consisting of several parts which possess different properties, and among these properties two of the most important are, difference of degrees of refrangibility, and difference of colour. This is demonstrated by some extremely beautiful and interesting experiments made with glass prisms.

If a ray of light be admitted into a dark chamber, through an opening P in a window shutter (*fig.* 195.) and be received at Q, upon the side of a triangular prism, it will, after passing through the prism, be separated into a fan-shaped bundle of rays, which may be received upon a screen at a distance from the prism.

If the ray were not intercepted by the prism, it would proceed along the dotted line, and would produce a luminous spot upon the screen at Z; but by the refraction of the prism, it is not only deflected to a higher point of the screen, but it is resolved into a number of divergent rays, the highest of which goes to K, and the lowest to K′, the intermediate rays falling upon the parts of the screen between K and K′. An appearance will be thus formed upon the screen, consisting of an oblong luminous band M N, the several parts of

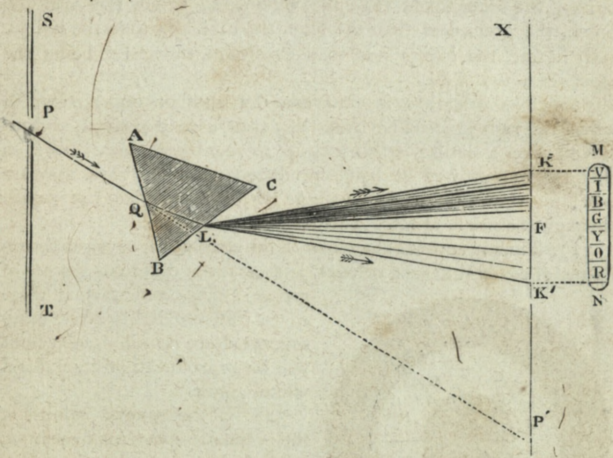


Fig. 195.

which have different colours. The colour at the summit is Violet, V, and at the lowest point Red, R; the intermediate colours proceeding downwards are Indigo, I; Blue, B; Green, G; Yellow, Y; and Orange, O.

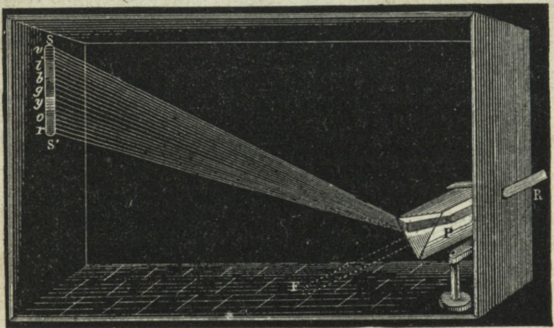


Fig. 196.

The arrangement by which this remarkable experiment is usually made, is represented in perspective in *fig.* 196.

325. The phenomenon here produced, which is called the *prismatic spectrum*, is explained, by supposing that the solar light consists of seven different component parts, having the seven different colours here indicated. These parts not only differ in colour, but also in refrangibility, since it is evident by mere inspection of the figures, that the red ray is less refracted than the orange, the orange less than the yellow, the yellow less than the green, the green less than the blue, the blue less than the indigo, and, in fine, the indigo less than the violet, the violet being the most refracted of all.

326. This inference is confirmed by another experiment, in which the rays proceeding from the prism here described, are received upon a similar prism with its refracting angle reversed, so that the opposite effect being produced upon the rays, they are recomposed and reduced to a single ray, as if they had not passed through the prism at all. This single ray is white.

327. Thus it appears that solar light consists of seven different lights, of seven different colours, and of seven different legrees of refrangibility, and that if these seven different lights after being separated are reunited, solar light will be reproduced of its natural white colour.

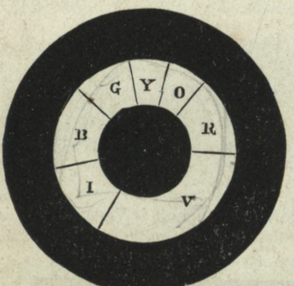


Fig. 197.

328. If the several colours of the prismatic spectrum be painted in a circle upon a screen, as represented in *fig.* 197., the spaces allotted to each colour corresponding with those which they occupy in the spectrum, their recombination can be produced by attaching the card upon which they are painted to a whirling apparatus as in *fig.* 198.

When the card is made to revolve with a rapid motion, any one of the coloured spaces alone would produce the appearance of a continuous ring of that colour; and when all are made to revolve together, such rings will be, as it were, superposed and mixed, and will produce a white colour.

329. If a white object be placed before a double convex lens, its image produced on the other side of the lens will not be, strictly speaking, single, as has been already stated, since the distance of the image from the lens will depend upon the refrangibility of the light proceeding from the object. But since the white light emitted from the object consists of seven component parts, having

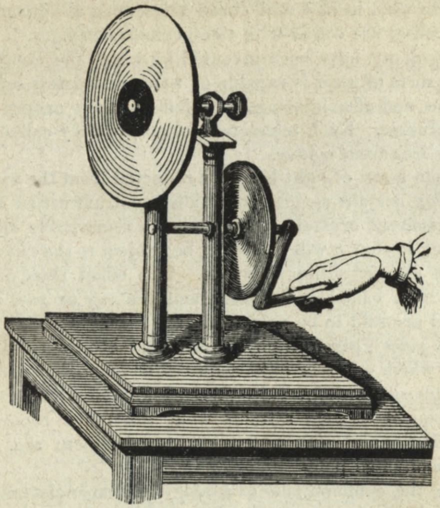


Fig. 198.

seven different degrees of refrangibility, that which is most refrangible will form an image near to the lens, and that which is least refrangible at a greater distance from it, those of intermediate refrangibility having images at intermediate distances.

Thus, if A C (*fig.* 199.) be the lens, the series of coloured images produced by a white object will have the order represented between V and R, the violet image being nearest the lens, and the red image most distant from it. But, since the images, though at different distances from the lens, are, nevertheless, still very close together they are seen as if they were superposed, and their colours are consequently blended, so that they will produce an image of the object in its natural colours, but more or less confused, and fringed at the edges with prismatic colours.

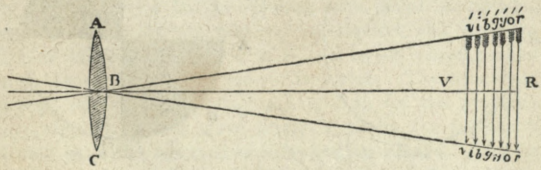


Fig. 199.

330. This is the reason why objects seen through a piece of cut glass are observed to be edged with colours like those of the rain-

bow, and also why, in bad and cheap telescopes, the images of all objects looked at are edged with these coloured fringes.

331. Expedients have been invented by which the combination of different sorts of glass is capable of neutralising this separation of the images, and of exhibiting the objects in their proper colours without confusion. Such telescopes are accordingly called *achromatic*, being free from colour.

332. When a ray of light has been reflected from the surface of a body under certain special conditions, or transmitted through certain transparent crystals, it undergoes a remarkable change in its properties, so that it will no longer be subject to the same effects of reflection and refraction as before. The effect thus produced upon it has been called *polarisation*, and the ray or rays of light thus affected are said to be *polarised*.

The name *poles* is given in physics in general to the sides or ends of any body which enjoy or have acquired any contrary properties. Thus, the opposite ends or sides of a magnet have contrary properties, inasmuch as each attracts what the other repels. The opposite ends of an electric or galvanic arrangement are, for like reasons, denominated poles.

Following the common rule of analogy in nomenclature, a ray of light which has been submitted to reflection or transmission under the special conditions referred to, has been called *polarised light*; inasmuch as it is found that the sides of the ray which lie at right angles to each other possess contrary physical properties, while those of a ray of common or unpolarised light possess the same physical properties.

To illustrate the relative physical condition of common light and polarised light, we may compare a ray of common light to a round rod or wire of uniform polish and uniformly white, while a ray of polarised light may be compared to a similar wire, two of whose opposite sides are rough and black,

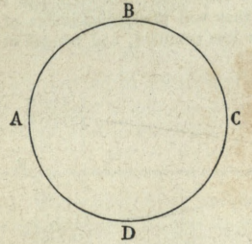


Fig. 200.

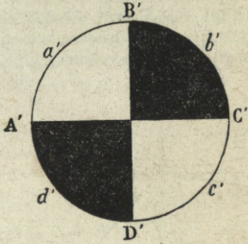


Fig. 201.

while the other opposite sides at right angles to these are polished and white. Thus, if A B C D (*fig.* 200.) be a section of the former, the entire circumference A B C D is white and polished, and if A′ B′ C′ D′ (*fig.* 201.) be a section of the latter, *a′* and *c′* will be white and polished, while *b′* and *d′* will be black and rough.

A group of physical properties, very numerous and complicated, characterise the polarised state of light, the discussion and exposition of which constitute the subject of an extensive and important section of optics.

333. Common light may be polarised either by reflection or refraction.

If a ray of light fall upon the surface of glass, blackened at the back, at an angle of 35° 25′ with the surface, the reflected ray will be polarised.

This angle is called the *angle of polarisation* for glass. Each body which reflects light has an angle of polarisation peculiar to it.

The polarised ray will be capable of reflection on the sides *a′ c′* (*fig*. 201.), at which it strikes the polarising surface, but incapable of reflection on the sides *b′ d′* at right angles to these, the angle of incidence being the same.

334. Light may be polarised by refraction, by transmitting the ray successively through a series of transparent plates, or through media called double refracting crystals.

335. Certain crystals, such as rock crystal, have the property of resolving a ray of common light transmitted through them into two rays, both of which are polarised. but so that the poles of the one are at right angles to those of the other. Thus, according to the illustration (*fig*. 201.), *a′* and *c′* would be white in one, and black in the other; while *b′* and *d′* would be black in the former, and white in the latter.*

336. When rays of light intersect each other under certain conditions, they are attended with the singular effect of extinguishing each other and producing darkness. This phenomenon is called the *interference of light.**

337. When a ray of light passes at the edge of an opaque body it is bent out of its course, either inwards or outwards. This phenomenon is called *inflection* or *diffraction.**

338. *Structure of the eye.* — In the human race the organ of vision consists of two hollow spheres, each about an inch in diameter, filled with certain transparent liquids, and deposited in cavities of suitable magnitude and form in the upper part of the front of the skull, on each side of the nose. These cavities are lined with soft matter, serving as a cushion for the protection of the eyeballs, which can move freely in them, the surface being lubricated by fluids secreted in surrounding glands. The organs are further protected from external injury by the projecting bones of the forehead above, forming the brows, the bones of the tem-

* See Handbook "Optics," chap. viii. to xi.

ples on the outside, those of the cheeks below, and those of the nose on the inside.

The form of the eyeball is nearly spherical, and the transparent liquids called *humours*, which fill its internal cavities, are inclosed in a triple membranous envelope.

The external coat, called the *sclerotica*, upon which the maintenance of the form of the eye chiefly depends, is a strong, opaque, tough structure, composed of bundles of strong white fibres, interlacing each other in all directions. This membrane covers about four fifths of the external surface of the eyeball, leaving, however, two circular openings; a large one in front, which is covered by a transparent convex piece of nearly uniform thickness, called the *cornea*, and a smaller one behind, which is the embouchure of the nerve called the *optic nerve*, which, proceeding backwards and upwards, and, passing through foramina in the bones of the skull, terminates in the brain. It is by this nerve that the impressions made by external objects on the organ of vision are transmitted to the brain.

The cornea is closely united at its edge with the corresponding edge of the circular opening in the sclerotica. It projects outwards in front of the eye, rendering that axis of the eye which passes through its centre a little longer than the diameter, which is at right angles to it. The cornea being of nearly uniform thickness, the concavity of its inner surface corresponds with the convexity of its outer, and gives the whole the character and form of a watch-glass, or a concavo-convex lens, whose surfaces have equal radii.

339. *Optic axis.*—In looking at an open eye, that part of the

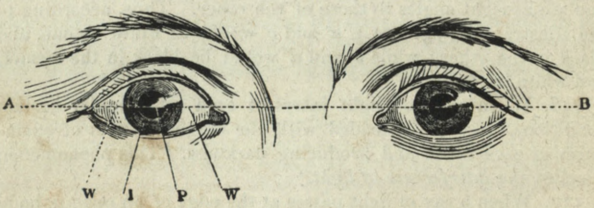


Fig. 202.

sclerotica which is uncovered is what is popularly called the white of the eye, and the cornea covers the coloured part.

A front view of the eyes and surrounding parts is shown in *fig.* 202., a section of them, made by a horizontal plane through the line A B passing through the centre of the front of the eyeballs, being shown in *fig.* 203.

The sclerotica is shown at C D F E, and the cornea at D G F.

A line M T, drawn through the centre of the cornea and the centre of the eyeball is called the *optic axis*, and the embouchure C E of the optic nerve lies at the distance of about the tenth of an inch from this axis, between it and the nose. The optic nerves R, therefore, issuing from the two eyeballs at the corners, beside and behind the nose, proceed in a converging direction to the brain, as shown in *fig.* 203.

340. The manner in which the globe of the eye is connected with the brain by the optic nerve, is shown in *fig.* 204., where S is the eyeball, the end

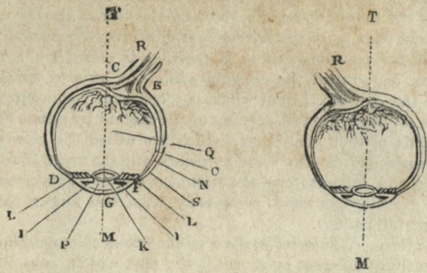


Fig. 203.

of the optic nerve entering its posterior part, and receding backwards from thence to the brain. The other nerves here represented as terminating in the eyeball are those which govern the motion of the several muscles which

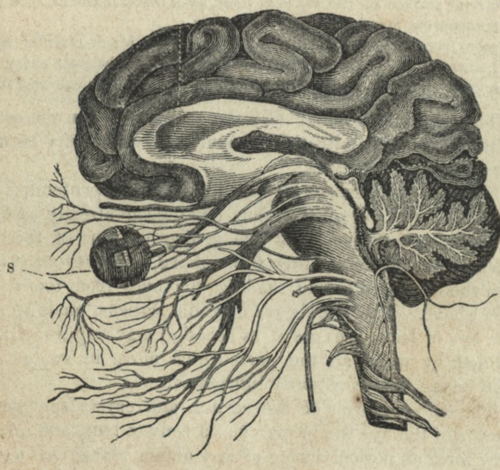


Fig. 204.

direct the movements of the eye. Within the sclerotica, and in contact with it, is the second coat, called the *choroid* N (*fig.* 203.), which is a dark-coloured vascular membrane, having openings before and behind corresponding with the cornea and optic nerve, similar exactly to those of the sclerotica.

341. Within this choroid is the third membranous coating (*fig.* 203.), called the *retina*, which is, in fact, the continuation of the fibres of the optic nerve spreading over the chief part of the internal surface of the eyeball. The retina is a delicate, pulpy, and perfectly transparent membrane. It is

spread over all the posterior and lateral parts of the surface, terminating near the margin of the frontal opening covered by the cornea already described.

As the frontal opening of the sclerotica is closed by the cornea, that of the choroid which corresponds with it in position is closed by a transparent double convex lens, called the *crystalline lens*, the axis of which coincides exactly with the optic axis, and which is consequently concentric with the cornea. It is set in the frontal opening of the choroid by means of a series of converging folds of that membrane, which are called the *ciliary processes*. The annular surface formed by these processes, and the crystalline lens which they surround and support, form the posterior side of a compartment in the front of the eyeball, separated completely from the larger compartment behind the crystalline lens.

342. The external or anterior surface of the iris is coloured blue, black, or hazel, differently in different eyes, and is the part which, seen through the transparent cornea, gives the characteristic colour to the eye.

The circular opening surrounded by the iris is called the *pupil*, and is the space through which the light, received through the cornea, is transmitted to the crystalline lens. By this means a pencil of rays is admitted to the crystalline whose external limits are determined by the edges of the iris.

The posterior surface of the iris is covered by a black pigment, contained in a thin transparent membrane, called the *uvea*.

When seen from the front, the pupil appears as a black circular spot P (*fig.* 202.), surrounded by the coloured ring of the iris, because every part of the interior of the eye which could be visible through it is coloured black.

343. The aqueous humour fills the space between the cornea and crystalline, and the vitreous humour fills the cavity between the crystalline and the retina.

344. Some of the accessories provided for the protection and preservation of the organ of vision have been already noticed. The eyebrows across the edge of the projecting part of the forehead catch the sweat descending from above, and prevent it from falling on the eyes, and aid in shading the eyes from too intense light from above. The eyelids are movable screens, made so as to cover the eye or leave it exposed, as occasion may require. Glands are provided, by which all the parts which move in contact one with another are kept constantly lubricated.

345. The convex forms of the cornea and crystalline give to the humours of the eye the property of a convex lens, and accordingly they form an optical image of any object placed before the eye; and in eyes which are not defective this image is formed on the posterior part of the retina, its centre coinciding with the point where the optic axis meets that membrane. Like the image produced by a lens it is inverted.

346. That this phenomenon is actually produced in the interior of the eye may be rendered experimentally manifest by taking the eyeball of an ox recently killed, and dissecting the posterior part, so as to lay bare the choroid. If the eye thus prepared be fixed in an aperture in a screen (*fig.* 205.), and a candle be placed before it at a distance of eighteen or twenty inches, an inverted image

of the candle will be seen through the choroid, as if it were produced upon ground glass or oiled paper.

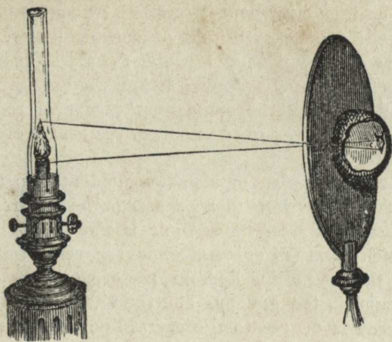


Fig. 205.

347. The most frequent defects incidental to vision are those which are denominated weak sight and short sight.

348. The cause of *weak sight* is the insufficiency of the refractive power of the eye, so that, instead of producing the image of visible objects upon the retina, that image would be formed at a greater or less distance behind the retina, the consequence of which is, that instead of a distinct image, a spot more or less confused is formed on the retina, just as would be the case if a screen were held behind a convex lens at a point nearer to it than its focus.

349. *Short sight*, on the contrary, arises from the humours of the eye having too great a refractive power, so that the image, instead of being formed on the retina, is formed at some point between the retina and the crystalline lens. The result is the same as in the former case, a more or less confused image of the object being formed on the retina, just as would be the case if a screen were held behind a convex lens at a point further from it than that at which the distinct image is formed.

350. The obvious remedy for weak sight is supplied by any expedient by which the refracting power of the eye can be increased, and this object is evidently attained by placing before the eye a convex lens. Such a lens, having always a tendency to increase the convergence of rays which pass through it, necessarily increases the convergence of all rays proceeding from external objects, and adds in effect to the refractive power of the eye.

By a proper adaptation, therefore, of convex lenses, the images of visible objects, instead of being formed behind the retina, will be formed upon it.

351. Spectacles, therefore, for a weak-sighted person consist of a pair of convex lenses so mounted that they can be conveniently applied in front of the pupil of the eye, so that all objects placed before the wearer may be looked at through them.

352. The remedy for the contrary defect of short sight is an expedient by which the convergent power of the eye may be lessened, and such an expedient is supplied by concave lenses, which, having an effect contrary to that of convex lenses, diminish the convergence of rays passing through them. A pair of concave lenses, therefore, properly applied before the eyes of short-sighted persons, will diminish the convergent power of the organ, and throw the images of objects back from the centre of the eye upon the retina.

353. In a certain class of maladies incidental to the sight, the humours of the eye lose in a greater or less degree their transparency, and the crystalline humour is more especially liable to this. In such cases vision is sometimes recovered by means of the removal of the crystalline humour, the organ being thus reduced to two humours, the aqueous and the vitreous; but as the eye owes in a greater degree to the crystalline than to the other humours the convergent power, it is necessary in this case to supply the place of the crystalline by a very strong convergent lens placed before the eye.

354. When the eye is impressed by any visible object, the impression continues upon the retina for a certain short interval of time after the object has been removed. This is rendered manifest by the familiar experiment of whirling a lighted stick in a circle. The circle appears a continued line of light. The explanation of this phenomenon is, that the impression produced upon the retina when the lighted stick is at any one point of the circle, continues till the stick returns to the same point; and this being the case for all the parts of the circle, the eye sees as it were the stick at the same moment at every part of the circle, and thus the circle presents a continued line of light.

355. This continuance of the impression of external objects on the retina, after tne light from the objects ceases to act, is also manifested by the fact that the continual winking of the eyes, for the purpose of lubricating the eyeball by the eyelid, does not intercept our vision. If we look at any external objects, they never cease for a moment to be visible to us, notwithstanding the frequent intermissions which take place in the action of light upon the retina, in consequence of its being thus intercepted by the eyelid.

356. In the same manner, a flash of lightning appears to the eye as a continuous line of light, because the impression produced upon the retina by the light at any point of its course continues until the light passes over a certain number of succeeding points.

357. But to produce this effect, it is not enough that the body change its position so rapidly, that the impression produced at one point of its path

continue until its arrival at another point; it is necessary, also, that its motion should not be so rapid, as to make it pass from any of the positions which it successively assumes, before it has time to impress the eye with a perception of it; for it must be remembered, as has been already explained, that the perception of a visible object presented to the eye, though rapid, is not instantaneous. The object must remain present before the organ of vision a certain definite time, and its image must continue upon the retina during such time, before any perception of it is obtained. Now, if the body move from its position before the lapse of this time, it necessarily follows that no perception of its presence will be obtained. If, then, we suppose a body moving so rapidly before the eye that it remains in no position long enough to produce a perception of it, such object will not be seen.

358. Hence it is that the ball discharged from a cannon, passing transversely to the line of vision, is not seen; but if the eye be placed in the direction in which the ball moves, so that the angular motion of the ball round the eye as a centre be slow, notwithstanding its great velocity, it will be visible, because, however rapid its real motion through space, its angular motion with respect to the eye (and consequently that of its picture on the retina) will be sufficiently slow to give the necessary time for the production of a perception of it.

359. The time thus necessary to obtain the perception of a visible object varies with the degree of illumination, the colour, and the apparent magnitude of the object. The more intense the illumination, the more vivid the colour, and the greater the apparent magnitude, the less will be the time necessary to produce a perception of the object.

If, therefore, the object before the eye be not sufficiently illuminated, or be not of a sufficiently bright colour to impress the retina sensibly, it will then, instead of appearing as a continuous line of colour, cease to be visible altogether; for it does not remain in any one position long enough to produce a sensible effect upon the retina.

360. If two railway trains pass each other with a certain velocity, a person looking out of the window of one of them will be unable to see the other. If the velocity be very moderate, and the light of the day sufficiently strong, the appearance of the passing train will be that of a flash of colour formed by the mixture of the prevailing colours of the vehicles composing it.

An expedient has already been described to show experimentally that the mixture of the seven prismatic colours, in their proper proportions, produces white light, depending on this principle. The colours are laid upon a circular disc surrounding its edge, which they divide into parts proportional to the spaces they occupy in the spectrum. When the disc is made to revolve, each colour produces, like the lighted stick, the impression of a continuous ring, and consequently the eye is sensible of seven rings of the several colours superposed one upon the other, which thus produce the effect of their combination, and appear as white, or a whitish grey colour, as already explained.

361. Innumerable optical toys and pyrotechnic apparatus owe their effect to this continuance of the impression upon the retina, when the object has changed its position.

Amusing toys, called thaumatropes, phenakisticopes, phantaskopes, &c., are explained upon this principle. A moving object, which assumes a suc-

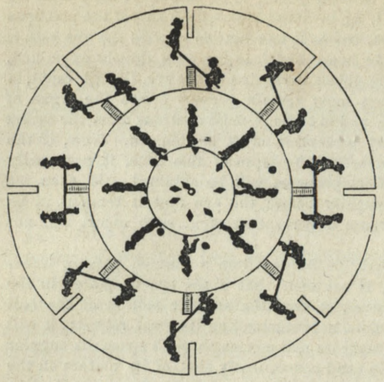


Fig. 206.

cession of different positions in performing any action, is represented in the successive divisions of the circumference of a circle, as in *fig.* 206., in the successive positions it assumes. These pictures, by causing the disc to revolve, are brought in rapid succession before an aperture, through which the eye is directed, so that the pictures representing the successive attitudes are brought one after another before the eye at such intervals that the impression of one shall remain until the impression of the next is produced. In this manner the eye never ceases to see the figure, but sees it in such a succession of attitudes as it would assume if it revolved. The effect is, that the figure actually appears to pirouette before the eye. The effects of catharine wheels and rockets are explained in the same manner.

362. Besides that imperfection incident to the organs of sight, arising from the excess or deficiency of their refractive powers, there is another class, which appears to depend upon the quality of the humours, through which the light proceeding from visible objects passes, before attaining the retina. It is evident that if these humours be not absolutely transparent and colourless, the image on the retina, though it may correspond in form and outline with the object, will not correspond in colour; for if the humours be not colourless, some constituents of the light proceeding from the object will be intercepted before reaching the retina, and the picture on the retina will accordingly be deprived of the colours thus intercepted. If, for example, the humours of the eye were so constituted as to intercept all the red and orange rays of white light, white paper, or any other white object, such as the sun, for example, would appear of a bluish-green colour; and if, on the other hand, the humours were so constituted as to intercept the blues and violets of white light, all white objects would appear to have a reddish hue. Such defects in the humours of the eye are fortunately rare, but not unprecedented.

Sir David Brewster, who has curiously examined and collected together cases of this kind, gives the following examples of these defects: —

A singular affection of the retina, in reference to colour, is shown in the inability of some eyes to distinguish certain colours of the spectrum. The persons who experience this defect have their eyes generally in a sound state, and are capable of performing all the most delicate functions of vision. Harris, a shoemaker at Allonby, was unable from his infancy to distinguish the cherries of a cherry-tree from its leaves, in so far as colour was concerned. Two of his brothers were equally defective in this respect, and always mistook orange for grass-green, and light green for yellow. Harris himself could only distinguish black and white. Mr. Scott, who describes his own case in the "Philosophical Transactions," mistook pink for a pale blue, and a full red for a full green.

All kinds of yellows and blues, except sky-blue, he could discern with great nicety. His father, his maternal uncle, one of his sisters, and her two sons, had all the same defect.

A tailor at Plymouth, whose case is described by Mr. Harvey, regarded the solar spectrum as consisting only of yellow and light blue; and he could distinguish with certainty only yellow, white, and green. He regarded indigo and Prussian blue as black.

Mr. R. Tucker described the colours of the spectrum as follows: —

Red mistaken for - - - - - - -	brown.
Orange ,, - - - - - - -	green.
Yellow sometimes - - - - - -	orange.
Green ,, - - - - - - -	orange.
Blue ,, - - - - - -	pink.
Indigo ,, - - - - - - -	purple.
Violet ,, - - - - - - -	purple.

A gentleman in the prime of life, whose case I had occasion to examine, saw only two colours in the spectrum, viz., yellow and blue. When the middle of the red space was absorbed by a blue glass, he saw the black space with what he called the yellow on each side of it. This defect in the perception of colour was experienced by the late Mr. Dugald Stewart, who could not perceive any difference in the colour of the scarlet fruit of the Siberian crab, and that of its leaves. Dr. Dalton was unable to distinguish blue from pink by daylight; and in the solar spectrum the red was scarcely visible, the rest of it appearing to consist of two colours. Mr. Troughton had the same defect, and was capable of fully appreciating only blue and yellow colours; and when he named colours, the names of blue and yellow corresponded to the more and less refrangible rays; all those which belong to the former exciting the sensation of blueness, and those which belong to the latter the sensation of yellowness.

363. *Case of Dr. Dalton.* — In almost all these cases, the different prismatic colours had the power of exciting the sensation of light, and giving a distinct vision of objects, excepting in the case of Dr. Dalton, who was said to be scarcely able to see the red extremity of the spectrum.

Dr. Dalton endeavoured to explain this peculiarity of vision, by supposing that in his own case the vitreous humour was blue, and therefore absorbed a great portion of the red and other least refrangible rays.

That this opinion was erroneous, however, was proved by the *post mortem* dissection of the eyes of that eminent person, by which it appeared that the vitreous humour was perfectly transparent and colourless.

Sir John Herschel attributes the defect of Dr. Dalton's vision, and other defects of the same class, to a morbid state of the sensorium, by which it is rendered incapable of appreciating exactly those differences between rays on which their colour depends.

364. When it is said that a certain object subtends at the eye a certain angle, it is meant that lines drawn from the extremities of such object to the centre of the eye form such angle.

The *apparent magnitude* of an object must not be confounded with its apparent superficial magnitude, the term being invariably applied to its *linear magnitude*. The apparent superficial magnitude varies in proportion to the square of the apparent magnitude.

Thus, for example, when the disc A B is removed to double its

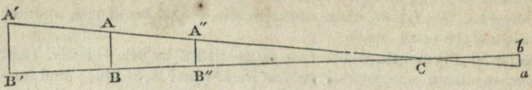


Fig. 207.

original distance from the eye, the apparent magnitude, or the angle C, is diminished one half, and consequently the diameter *a b* of the picture on the retina is also diminished one half; and since the diameter is diminished in the ratio of 2 to 1, the superficial magnitude of the image, or its area, will be diminished in the proportion of 4 to 1.

365. It is clear from what has been stated also, that when the same object is moved from or towards the eye, its apparent magnitude varies inversely as its distance; that is, its apparent magnitude is increased in the same proportion as its distance is diminished, and *vice versâ*.

It is easy to perceive that the objects which are seen under the same visual angle will have the same apparent magnitude. Thus, let A′ B′ (*fig.* 207.) be an object more distant than A B, and of such a magnitude that its highest point A′ shall be in the continuation of the line C A, and its lowest point B in the continuation of the line C B. The apparent magnitude of A′ B′ will then be measured by the angle at C. This angle will therefore at the same time represent the apparent magnitude of the object A B and of the object A′ B′. It is evident that an eye placed at C will see every point of the object A B upon the corresponding points of the object A′ B′; so that if the object A B were opaque, and of a form similar to the object A′ B′, every point of the one would be seen upon a corresponding point of the other. In like manner, if an object A″ B″ were placed nearer the eye than A B, so that its highest point may lie upon the line C A, and its lowest point upon the line C B, the object, being similar in form to A B, would appear to be of the same magnitude. Now it is evident that the real magnitudes of the three objects A″ B″, A B, and A′ B′, are in proportion to their respective distances from the eye; A′ B′ is just so much greater than A B, and A B than A″ B″, as C B′ is greater than C B, and as C B is greater than C B″.

Thus it appears that if several objects be placed before the eye in the same direction at different distances, and that the real linear magnitudes of these objects are in the proportion of their distances, they will have the same apparent magnitude.

366. *Example of the sun and moon.* — A striking example of this principle is presented by the case of the sun and moon. These objects appear in the heavens equal in size, the full moon being equal in apparent magnitude to the sun. Now it is proved by astronomical observation that the real diameter of the sun is, in round numbers, four hundred times that of the moon; but it is also proved that the distance of the sun from the earth is also, in round numbers, four hundred times greater than that of the moon. The distance, therefore, of these two objects being in the same proportion as their real diameter, their visual or apparent magnitudes are equal.

367. Optical instruments contrived to increase the powers of the natural vision may be resolved into two classes; the first being those which enable us to see objects which, though near, are too minute to be distinctly seen with the naked eye; and the second, those which enable us to see objects which, though of sufficient magnitude, are too remote to be distinctly visible. The former are called *microscopes*, and the latter *telescopes*.

368. Since the visual or apparent magnitude of an object is the angle which it subtends at the eye, and since, by bringing an object, however minute it may be, closer and closer to the eye, this visual angle may be indefinitely augmented, it might appear, since the visual magnitude of a minute object may thus be indefinitely increased, that it might be rendered distinctly visible without the intervention of any optical contrivance; and this would in fact be the case but for a circumstance which we shall now explain.

It has been already stated that a picture of an object placed before the eye is formed on the retina, and upon the distinctness of this picture depends the distinctness of vision; but as the object approaches the eye, the conjugate focus at which its image is formed recedes from the crystalline, and a distinct image is formed on the retina, only when the distance of the object from the eye is such as to bring the conjugate focus there. Now it is found that when this distance is less than ten inches in average eyes, and less than five or six inches in short-sighted eyes, the conjugate focus would be behind the retina, and consequently the image of the object formed on the retina would be confused or indistinct according to what has been already explained. It appears, therefore, that without some optical expedient to correct these consequences, no object placed within a very small distance of the eye can be distinctly visible.

369. To bring the image formed behind the eye forward to the retina, it is therefore necessary to interpose a lens which will have the effect of augmenting the convergent power of the eye. This will be more readily understood by the diagram, *fig.* 208., where E represents a section of the eye.

Let E E represent a section of the eye, and *o o'* a small object placed at a much less distance from the eye than is compatible with distinct vision. According to what has been explained, it will appear that the cause of indistinct vision is, in this case, that the image of *o o'*, produced by the humours of the eye, is formed, not as it ought to be on the retina at I I', but behind it at *i i'*. According to what has been explained of optical images, the interposition of a lens, L L, of suitable convexity, will bring forward the image from *i i'* to I I', and will therefore render the perception of the object distinct.

Now, it is most important to observe in this case, that the visual magni-

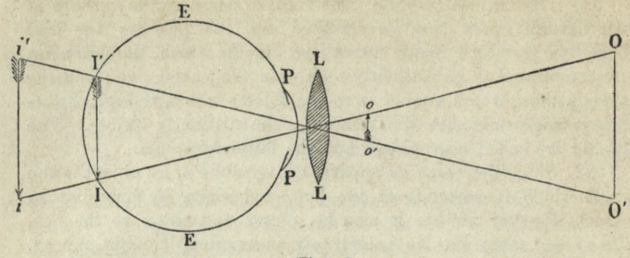


Fig. 208.

tude of the object, measured by the angle formed by the lines *o* I and *o'* I', will be exactly the same as it would be if the eye could have seen the object *o o'* without the interposition of the lens: from which it appears that the lens does not, as is commonly supposed, *directly* augment the visual magnitude of the object, but only enables the eye to see the object with distinctness, at a less distance than it could so see it without the interposition of the lens. We say *directly*, because, although the lens does not augment the visual angle of the object, in the position in which it is actually viewed, yet, by enabling the eye to see it distinctly at a diminished distance, the visual angle of distinct vision, and therefore the apparent magnitude of the object, is increased in exactly the same proportion as the distance at which it is viewed is diminished.

To understand the magnifying effect of the lens, we must consider that the observer, seeing the object *o o'* with perfect distinctness, obtains exactly the same visual perception of it, as if the object, having the same visual magnitude, were placed at that distance from the eye at which his vision would be most distinct. Let the lines passing through the extremities of the object, therefore, be prolonged to this distance of most distinct vision, and let an object, O O', be supposed to be placed there, similar in all respects to the object *o o'*, and having the same visual magnitude. It will be evident, from what has been stated, that *o o'*, as seen with the lens, will have precisely the same appearance as the object O O' would have if seen with the naked eye. The observer, therefore, considers, and rightly considers, that the magnifying power of the lens is expressed by the number of times that O O' is greater than *o o'*; or, what is the same, by the number of times that the distance of O O' from the lens, that is, the distance of most distinct vision, is greater than the distance of the object from the lens.

It follows, therefore, generally, that the magnifying power of the lens will be found by dividing the distance of most distinct vision (generally assumed as ten inches) by the distance of the object from the lens.

The most feeble class of magnifying glasses are those occasionally used for reading small type, by persons of very weak sight; they consist of double convex lenses of five or six inches focal length, and having, consequently, a magnifying power no greater than two; they are usually mounted in tortoise-shell or horn, with convenient handles.

370. Magnifiers of somewhat shorter focal length and less

diameter, similarly mounted, are used by miniature-painters and engravers.

Lenses having a focal length of about one inch, set in a horn cell, enlarged at one end like the wide end of a trumpet, the magnitude being made to correspond with the socket of the eye, as represented in *fig.* 209., are used by watchmakers. The wide end, being inserted under the eyebrow, is held in its position by the contraction of the muscles surrounding the eyeball, and the minute work to be examined, is held within an inch of the lens set in the smaller end of the horn case: if the focal length be an inch, the magnifying power of such a glass, for average eyes, will be ten.

Fig. 209.

Glasses somewhat similarly mounted are used by jewellers, gem-sculptors, and other artists.

371. When still higher magnifying powers are required, the instrument takes the name of a *microscope*.

Microscopes are of two kinds, *simple* and *compound*.

In the simple microscope, the object under examination is viewed directly, either by a simple or compound converging lens.

In the compound microscope, an optical image of the object, produced upon an enlarged scale, is thus viewed.

372. *Simple microscopes* are variously mounted with convenient appendages for supporting the object and adjusting its distance from the lens.

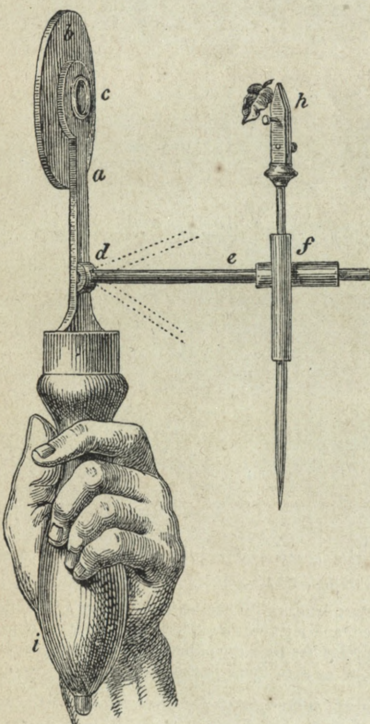


Fig 210.

One of the forms of this instrument is shown in *Fig.* 210., where the lens is inserted in a socket *c* made to fit it; the screen *b* protects the eye from the light by which the object is illuminated; an arm *e* is jointed at *d*, so that it can be turned flat against *a*, when the instrument is not in use, and can be inclined to *a*, at any desired angle. This arm being round, a sliding tube *f* is placed upon it, fixed to another tube at right angles to it, in which a vertical rod slides, to the upper end of which is attached a forceps *h* or any other convenient support of the object under examination.

Several magnifiers of various powers may be provided, any of which may be inserted at pleasure in the socket *c*.

373. Another arrangement in which the object supported on a stage can be raised and lowered, so as to be brought near to or farther from the lens, and by which it can be illuminated by a reflector M, is shown in *fig.* 211.

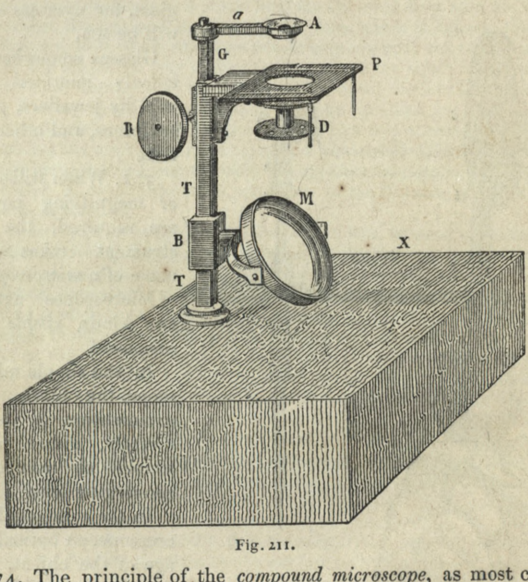


Fig. 211.

374. The principle of the *compound microscope*, as most commonly used, is illustrated in *fig.* 212.

O is the object, L L the convex lens, called the *object lens*, by which the magnified image O O is formed, and E E the magnifier by which this object O O is viewed. According to what has been explained, the apparent magnitude of the minute object O O, when seen through the lens E E, will be O O′.

375. The telescope is an instrument by means of which an object is viewed distinctly which cannot be so viewed by the

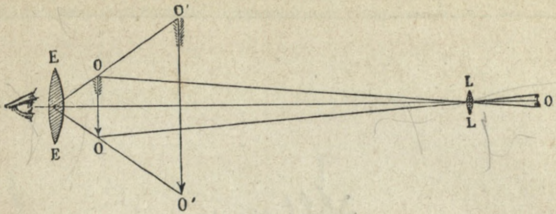


Fig. 212.

naked eye, by reason of its distance. The term is derived from two Greek words, τηλε (télé), *at a distance*, and σκοπεω, *I view.*

Its principle is identical with that of the compound microscope. An optical image of the object to be viewed is produced by means of a concave reflector, or a converging lens; and this image is then submitted to observation with a miscroscope composed of one or more converging lenses.

Telescopes consist, therefore, of two classes, Reflectors and Refractors; the image being produced in the former class by concave reflectors, and in the latter by convex lenses.

376. In the reflecting telescope, a large concave metallic reflector is presented towards the object, an optical image of which is produced in its focus, and this image is viewed with a magnifying lens, as has been already explained in the compound microscope.

377. A form of reflecting telescope, called the *Gregorian*, is shown in section in *fig.* 213.

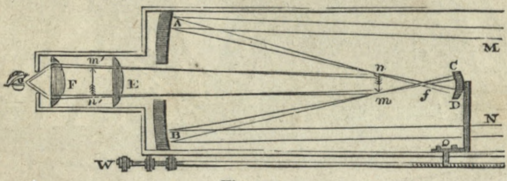


Fig. 213.

A B is the great concave reflector, *m n* the image formed by it, C D a small concave reflector, which reflects the rays proceeding from *m n* to a convex

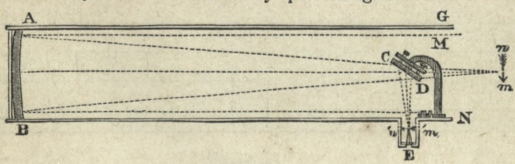


Fig. 214.

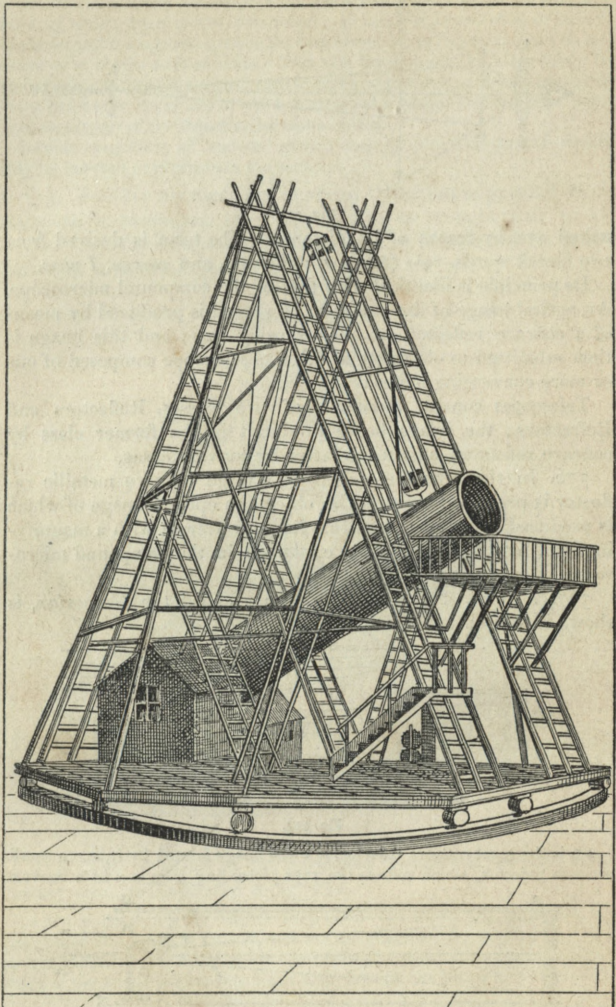


Fig. 215.

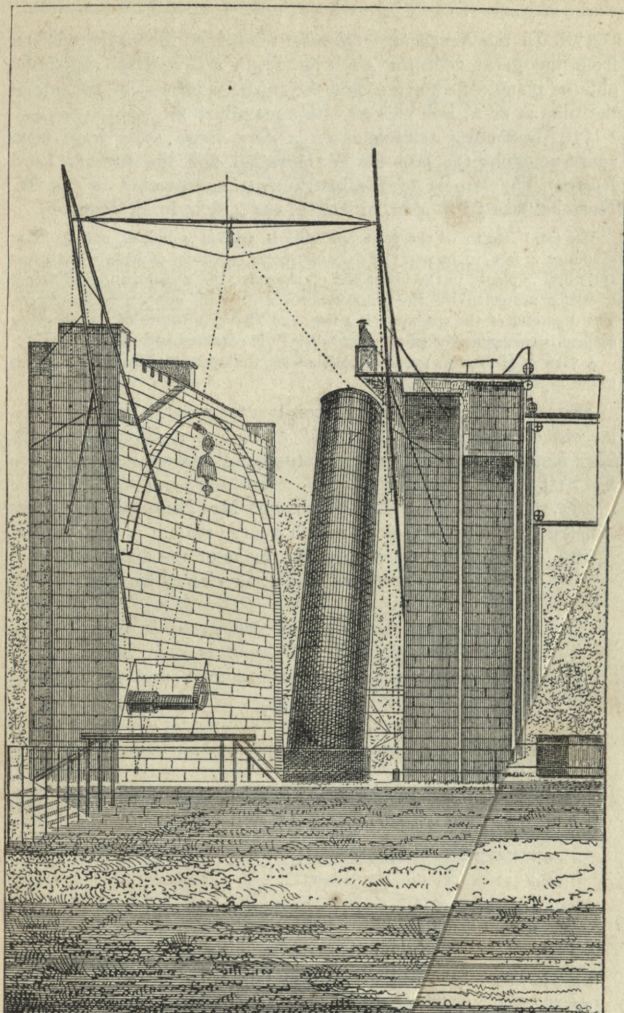


Fig. 216.

lens E, by which an enlarged image $m' n'$ is formed. This image is viewed with a magnifier F.

378. In the *Newtonian reflecting* telescope, the rays reflected from the great reflector A B (*fig.* 214.) are received upon the oblique plane reflector C D, and the image is formed in the side of the tube at $m' n'$, and viewed with a magnifier E.

379. Reflecting telescopes on a very large scale have been constructed by the late Sir W. Herschel and the present Lord Rosse. The largest of the instruments constructed by Sir W. Herschel was 39 ft. 4 in. in length, and 4 ft. 4 in. in diameter.

The total length of the telescope tube is 39 feet 4 inches, and its clear diameter 4 feet 10 inches. It is constructed entirely of iron. The great speculum is placed in the lower end of the tube, the apparatus for adjusting it being protected by the wooden structure which appears in the figure. The diameter of the speculum is 4 feet, and the magnitude of its reflecting surface is consequently 12·566 square feet. It contains 1050 lbs. of metal.

A view of Herschel's great telescope with the apparatus for elevating it is given in *fig.* 215.

380. The Earl of Rosse has constructed several telescopes, the largest of which has a length of 53 ft. and a diameter of 6 ft. This instrument, with the apparatus for elevating it, is shown in *fig.* 216.

381. Mr. Lassell, of Liverpool, and Mr. Nasmyth, have also constructed reflecting telescopes on a large scale.

382. In refracting telescopes, the image of the distant object is formed by a large convex lens, and it is viewed by a magnifying lens called the eye glass.

383. Refracting telescopes are of two kinds, in one of which the eye glass is concave, and the object is seen in its natural position; in the other the eye glass is convex, and the object is seen inverted.

384. The former is called from its inventor *Galilean*, and is familiar to every one, the common *opera glass* being an example of it on a small scale.

The principle of this telescope is illustrated in *fig.* 217., where the image of a distant object M N is produced at $m\ n$, in the focus of a double convex

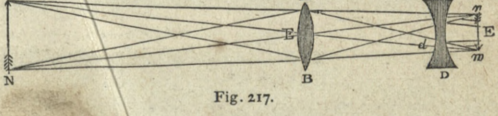


Fig. 217.

lens A B, called the object glass; but the rays before forming the image are received on the double concave eye glass C D: the observer sees the image distinctly as it would appear at a distance equal to the focal length of the eye glass.

385. The other form of the refracting telescope, called the *astronomical telescope*, is illustrated in *fig.* 218.

The image of a distant object M N is produced at *m n* by the object glass A B, and viewed through a convex lens C D, called the eye glass, the distance of the latter from the image being its focal length. The effect of C D on the image is explained in the same manner as that of a common magnifying glass.

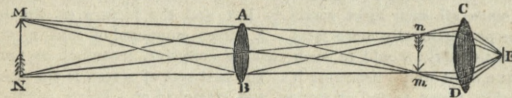


Fig. 218.

386. The magic lantern is an optical instrument adapted for magnifying pictures, painted on glass in transparent colours, by means of magnifying lenses.

When a picture, or other object, is placed in front of a convex lens, at a distance from it somewhat greater than its focal length, such picture or object will be reproduced upon a screen, placed at a certain distance behind the lens, that distance being greater, the nearer the picture in front of the lens is to its principal focus. This is the principle upon which the magic lantern is constructed.

387. It varies in form and arrangement, according to its price and the circumstances under which it is used, but in general consists of a dark lantern, *fig.* 219., within which a strong lamp L is placed, having a chimney bent at

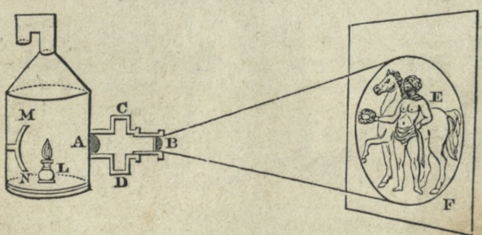


Fig. 219.

the top, to allow the smoke and heated air to escape, while the light is intercepted.

In front of the lamp, and on a level with its flame, a tube is inserted, in which a large convex lens A is fixed, by means of which the light of the lamp is condensed upon the picture placed opposite the lens A, by sliding it through a groove, C D. From this mode of fixing the picture, the latter has generally been called a "slider." In the tube thus projecting from the lantern, another tube is fitted sliding in it, as one tube of an opera glass slides in the other. At the end of this second tube a convex lens B is set, and the tube is so adjusted that the distance of B from the picture shall be a little greater than the focal length of the lens B. A large screen F, made of white canvas, which may be much improved by covering it with paper, is then placed at a distance from B, and at right angles to the axis of the lens.

By properly adjusting the tube B, and the distance of the screen F, the picture upon the slider in C D will be reproduced at E upon the screen, on an enlarged scale.

388. There are two ways of exhibiting the pictures on a screen: in one, the lantern is placed in front of the screen; in that case the picture is seen by the light reflected from the screen, after having been projected upon it by the lantern.

Care should, therefore, be taken that no light shall penetrate through the screen, since all such light would be lost, and the picture on the screen would be proportionally more faint. A screen composed of muslin, or any other textile fabric, would in such case be defective, inasmuch as more or less of the light would penetrate it. The best sort of screen is one made of strong white paper, pasted on canvas, and stretched on a frame, as canvas is for a picture.

When the magic lantern is used for purposes of amusement, rather than those of instruction, it is generally found desirable to use a semi-transparent screen, the lantern being mounted on one side of the screen, and the spectators placed on the other, as shown in *fig.* 220. In this case, the screen

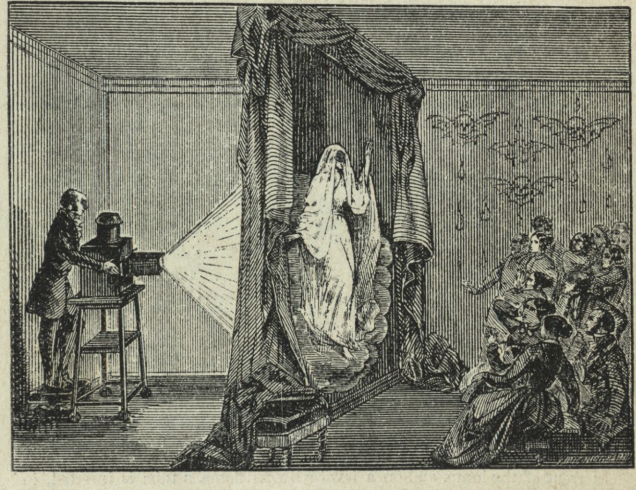


Fig. 220.

should be made of white muslin or fine calico, stretched upon a frame, its transparency being increased by wetting it well with water. In some cases the muslin is prepared with wax or oil, which may be convenient to save the trouble of wetting it, but which in other respects does not answer the purpose better.

389. *Dissolving views.* — Interesting and amusing effects are produced by placing two lanterns of equal power, so as to throw pictures of precisely equal magnitude on the same part of the same screen. A sliding cover is placed in front of the nozzle of each of the lanterns, and these are moved

simultaneously in such a manner, that when the nozzle of one lantern is completely opened, that of the other is completely closed, so that, according as the former is gradually closed, the latter is gradually opened.

To illustrate this class of effects, which always create an agreeable surprise, let us suppose that two sliders are placed in the lanterns, one representing a landscape by day, and the other representing precisely the same landscape by night, and let the nozzle of that which contains the day landscape be opened, the other being closed: the picture on the screen will then represent the day landscape. If the covers of the nozzles be now slowly moved, so that that of the lantern which shows the day landscape shall be gradually closed, and that of the other shall be gradually opened, the effect on the screen will be that the daylight will gradually decline, the view assuming, by slow degrees, the appearance of approaching night. This gradual change will go on, until the nozzle of the lantern containing the day picture has been completely closed, and that containing the night picture completely opened, when the change from day to night will be accomplished, the picture on the screen being then a night landscape.

The optical effect produced by two lanterns working together, called *dissolving views*, with which the public has been rendered familiar at several of the public institutions in London, depends on the alternate opening and closing of the nozzles of two lanterns, in the manner here described. The mistiness and confusion which is exhibited in the gradual disappearance of the one view, and the gradual appearance of the other, arises from the circumstance of the nozzles of both lanterns being partially open at the same moment, so that both views, faintly illuminated, are projected upon the screen at the same time. The mixture of their outline and colours produces the mistiness and confusion, with which all spectators of such exhibitions are familiar. According as the nozzle of the lantern, which contains the disappearing view, is more and more closed, and that which contains the appearing view more and more open, the latter becomes more and more distinct, and becomes perfectly so, when the one lantern is completely closed, and the other is completely opened.

390. The *solar microscope* differs but little from the magic lantern; the pictures exhibited by it are those of minute objects, and consequently the lenses which form the image must be adapted to produce much larger images than in the magic lantern. The light by which the objects are illuminated is that of the sun, the rays of which are collected on the object by means of convex lenses

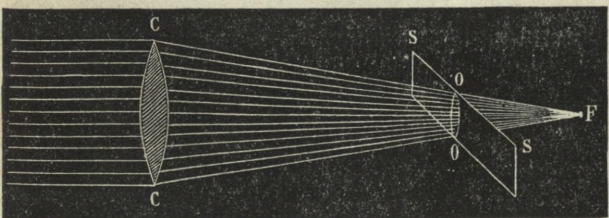


Fig. 221.

The effect is illustrated in *fig.* 221., where the solar rays received on the convex lens C C, are condensed upon the object O O, set in the slider S S.

391. The *camera obscura* is an instrument by which an optical picture of distant objects is formed, by means of a convex lens combined with a plane reflector.

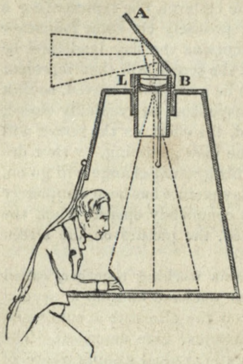


Fig. 222.

The principle of the instrument in one of its forms is illustrated in *fig.* 222., where A B is a plane reflector reflecting the rays downwards to the convex lens L B, by which an image is formed upon a table, where it can be traced by a draughtsman.

392. Other methods of mounting this instrument are shown in *figs.* 223, 224.

In the former case the picture is formed upon a semi-transparent plate of glass.

393. The *camera lucida* is an instrument by which a somewhat similar effect is produced, and which answers nearly the same purpose.

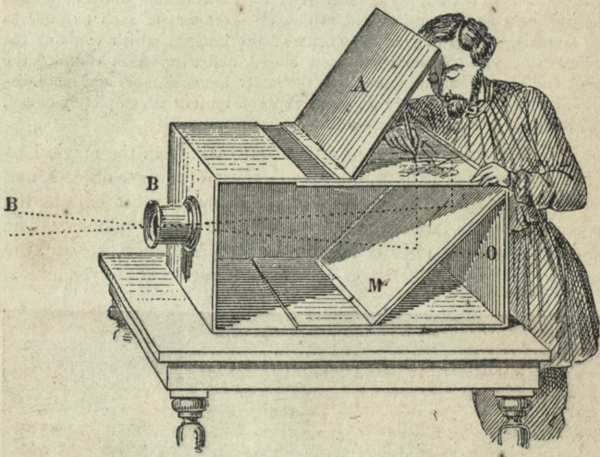


Fig. 223.

The rays from a distant object A B (*fig.* 225.), are received upon an oblique reflector M M′, by which they are reflected to the eye at E′, so that the eye sees a picture of the object A B projected downwards. A part of the reflector M M′ is transparent, and through it the observer sees the paper P P,

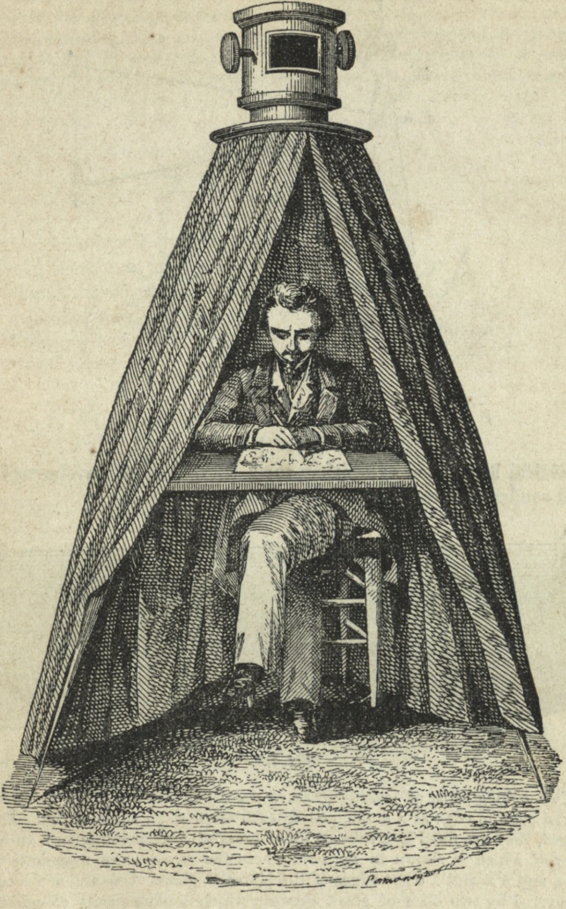


Fig. 224.

upon which the image A′ B′ is projected, so that he can trace the outline of the image with a pencil.

394. The pretty optical toy, called the kaleidoscope, named from three Greek words, *καλόν εἶδος* (kalon eidos), *a beautiful form*, and *σκοπέω* (skopeo), *I see*, was invented by Sir David Brewster, for the purpose of creating, in indefinite number and variety,

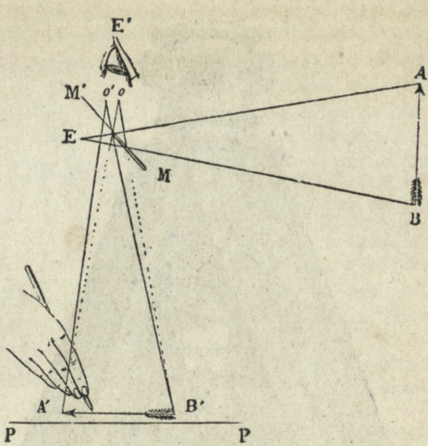


Fig. 225.

beautiful forms, and exhibiting them so that they may be copied and rendered permanent.

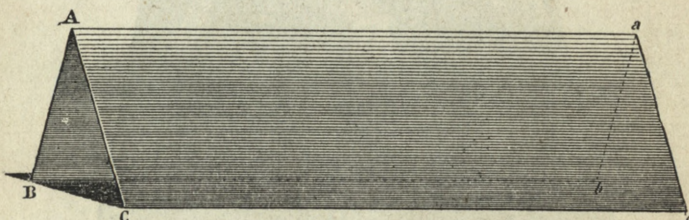


Fig. 226.

Two oblong slips of looking-glass, A *a* *c* C and A *a* *b* B (*fig.* 226.), are placed edge to edge at A *a* inclined to each other at an angle of 60°. Thus placed, they are fixed in a tube of tin or brass of corresponding size, an end view of which is shown in *fig.* 227., where the circle A C B represents the tube, and A B and A C the edges of the plates of glass. One end of the tube is covered by two discs of glass, between which broken pieces of coloured glass or other transparent coloured objects are placed loosely, so that they can fall from side to side, and take an infinite variety of casual arrangements. The external disc is ground glass, to prevent the view of external objects disturbing the effect. The other end of the tube is covered by a diaphragm, with a small eye hole in its centre, through which the observer looks at the coloured objects contained in the cell at the other end. He not only sees these objects, but also their reflection in each of the inclined glasses; and when the angle of inclination is 60°, the object will be seen five times repeated, in positions regularly disposed round the line formed by the edges at which the glasses touch each other.

The angular space, B A C, included between the glasses, and every object within it, will be seen reflected in each glass. Thus B A C will be seen in the glass B A, as if it were repeated in the space B A C′, and in the glass A C,

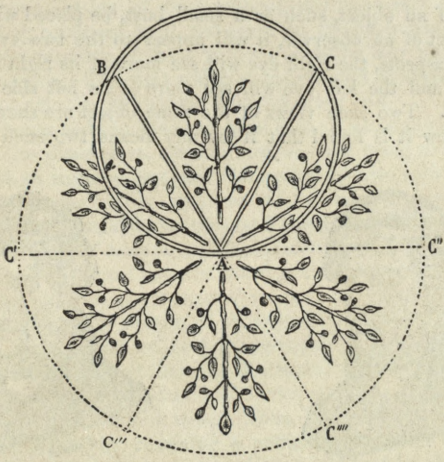


Fig. 227.

as if it were repeated in the space C A C″. But this is not all. The reflection B A C′ becomes an object before the glass A C, and being reflected by it, is reproduced in the space C″ A C⁗, and the reflection C A C″ being reflected by the glass A B, is reproduced in the space C′ A C‴. Thus, besides the view of the objects themselves which are between the glasses, and which would be seen if there were no reflection, the observer will see the four reflections, two, C A C″ and C″ A C⁗, to the right, and two, B A C′ and C′ A C‴, to the left.

But the reflection C′ A C‴ is again reflected by the glass A C, and is seen in the space C‴ A C⁗, and at the same time the reflection C″ A C⁗ is reflected in the glass A B, and is also reproduced in the same space C‴ A C⁗. Thus it appears that this space C‴ A C⁗ receives the reflection of both glasses.

The observer, looking through the eye hole of the kaleidoscope, sees a circle whose apparent diameter, C C‴, is twice A C, the breadth of the reflector. This circle is divided into six angular spaces, two of which are the first reflections, and other two the second reflections of the inclined glasses. The other two consist of the actual space included between the glasses, and a similar space opposite to it which receives at once the third reflection of both glasses.

Since looking glasses never reflect *all* the light incident upon them, these reflections will not be as vivid as the direct view of the space B C; nor will they, compared one with another, be equally vivid. The reflections B C′

and $c\,c''$ will be less vivid than the object $b\,c$, but more so than the second reflections $c'\,c'''$ and $c''\,c''''$. The third reflection $c'''\,c''''$ would be less vivid than the second $c'\,c'''$ and $c''\,c''''$, if it proceeded only from one glass, as do the latter. But it must be remembered that being the combined reflection of both glasses, the loss of brightness by the multiplied reflections of each glass is to some extent compensated.

395. If an object, such as a small bust, be placed within one or two feet of an observer, it will appear to the two eyes under different aspects, the right eye will see more of its right side than the left, and the left eye will see more of its left side than the right eye. Two such views of the same object are shown in *fig.* 228. Now it is found that if by any means two such pictures

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Fig. 228.

as these can be put before the eyes, so that the one shall be seen before the right eye only, while the other is seen by the left eye only, the impression produced will be that of the solid body itself. In short, so strong an impression of relief will be produced, as to constitute a complete optical illusion. This is, in general terms, the principle upon which the instrument called the *stereoscope*, with which every one is familiar, is constructed. Two such pictures as here described are placed in the instrument, and they are viewed through lenses which are so adapted, that the rays proceeding from them enter the eye as they would do, if they had actually proceeded from the single solid object represented by the pictures.

CHAP. XIII.

HEAT.

396. HEAT, like all other physical agents, is manifested and measured by its effects, one of the most familiar of which is the

sense of more or less warmth which a body, when it receives or loses heat, produces upon our organs. When the heat received or lost by a body is attended with this sense of increased or diminished warmth, it is called *sensible heat*.

397. But it will occur in certain cases that a body may receive a very large accession of heat without any increased sense of warmth being produced by it, and may, on the other hand, lose a considerable quantity of heat without exciting any diminished sense of warmth. The heat which a body would thus receive or lose without affecting the senses, is called *latent heat*.

398. When a body receives or loses heat, it generally suffers a change in its dimensions, the increase of heat being usually attended with an increase, and the diminution of heat with a diminution of volume. This enlargement of volume due to the accession of heat is called *dilatation*, and the diminution of volume attending the loss of heat is called *contraction*. There are, however, certain exceptional cases in which heat, whether received or lost, is attended with no change of volume, and others in which changes take place the reverse of those just mentioned; that is to say, where an accession of heat is accompanied by a diminution, and a loss of heat with an increase of volume.

399. If heat be imparted in sufficient quantity to a solid body, it will pass into the liquid state. Thus, ice or lead, being solid, will become liquid by receiving a sufficient accession of heat. This change is called *fusion* or *liquefaction*. If heat be abstracted in sufficient quantity from a body in the liquid state, it will pass into the solid state. Thus, water or molten lead losing heat in sufficient quantity will become solid. This change is called *congelation* or *solidification;* the former term being applied to substances which are usually liquid, and the latter to those that are usually solid.

400. If heat be imparted in sufficient quantity to a body in the liquid state, it will pass into the state of vapour. Thus, water being heated sufficiently will pass into the form of steam. This change is called *vaporisation*. If a body in the state of vapour lose heat in sufficient quantity, it will pass into the liquid state. Thus, if a certain quantity of heat be abstracted from steam, it will become water. This change is called *condensation;* because, in passing from the vaporous to the liquid state, the body always undergoes a very considerable diminution of volume, and therefore becomes condensed.

401. Heat, when imparted to bodies in a certain quantity, will in some cases render them luminous. Thus, if metal be heated to a certain degree, it will become *red hot;* a term signifying merely

that it emits red light. This luminous state, which is consequent on the accession of heat, is called *incandescence.*

The more intense the heat is which is imparted to an incandescent body, the more *white* will be the light which it emits. When it first becomes luminous, it emits a dusky red light. The redness becomes brighter as the heat is augmented, until at length, when the heat becomes extremely intense, it emits a white light resembling solar light. A bar of iron submitted to the action of a furnace will exhibit a succession of phenomena illustrative of this.

402. Certain bodies, when surrounded by atmospheric air, being heated to a certain degree, will enter into chemical combination with the oxygen gas which forms one of the constituents of the atmosphere. This combination will be attended with a large development of heat, which is accompanied usually by incandescence and flame. This phenomenon is called *combustion*, and the bodies which are susceptible of this effect are called *combustibles.* The flame, which is one of the effects of combustion, is gas rendered incandescent by heat.

403. The degree of sensible heat by which a body is affected, is called its *temperature*, and the instruments by which the temperature of bodies is indicated and measured are called *thermometers* and *pyrometers;* the latter term being applied to those which are adapted to the measurement of the higher order of temperatures.

Changes of temperature are indicated and measured by the change of volume which they produce upon bodies very susceptible of dilatation. Such bodies are called *thermoscopic bodies.* The principal of these are, for thermometers, mercury, alcohol, and air; and, for pyrometers, the metals, and especially those which are most difficult of fusion.

404. When heat is communicated to any part of a body, the temperature of that part is momentarily raised above the general temperature of the body. This excessive heat, however, is gradually transmitted from particle to particle throughout the entire volume, until it becomes uniformly diffused, and the temperature of the body becomes equalised. This quality, in virtue of which heat is transmitted from particle to particle throughout the volume of a body, is called *conductibility.*

Bodies have the quality of conductibility in different degrees; those being called good conductors in which any inequality of temperature is quickly equalised, the excess of heat being transmitted with great promptitude and facility from particle to particle. Those in which it passes more slowly and imperfectly through the dimensions of a body, and in which, therefore, the equilibrium of temperature is more slowly established, are called imperfect conductors. Bodies in which the excess of heat fails to be transmitted from particle to particle before it has been dissipated in other ways, are called non-conductors.

The metals in general are good conductors, but different metals have different degrees of conductibility. The earths and woods are bad conductors, and soft, porous, and spongy substances still worse.

405. Heat is propagated from bodies which contain it by radiation in the same manner, and according to nearly the same rules, as those which govern the radiation of light. Thus, it proceeds in straight lines from the points whence it emanates, diverging in every direction, these lines being called *thermal rays.*

406. Certain bodies are pervious to the rays of heat, just as glass and other transparent media are pervious to the rays of light. They are called *diathermanous* bodies. Thus atmospheric air and gaseous bodies in general are diathermanous.

The rays of heat are reflected and refracted according to the same laws as those of light. They are collected into foci by spherical mirrors and lenses, they are polarised both by reflection and refraction, and are subject to all the phenomena of double refraction by certain crystals in a manner analogous to that which takes place in relation to the rays of light.

Bodies are diathermanous in different degrees. Imperfectly diathermanous bodies transmit some of the rays of heat which impinge on them, and absorb others; the portions which they absorb raising their temperature, but those which they transmit not affecting their temperature.

407. The surfaces of bodies reflect heat in different degrees; those rays which they do not reflect they absorb. The degrees of transmission, absorption, and reflection vary with the nature of the body and the state of its surface with respect to smoothness, roughness, or colour.

408. Rays of heat, like those of light, are differently refrangible.

409. The term heat is used in different senses: first, to express the sensation produced when we touch a heated body or are surrounded by a hot medium; secondly, to express the quality of the body by which this sensation is produced; and, thirdly, to express the physical agent, whatever it be, to which the quality of the body is due. Notwithstanding these different senses of the same term, no confusion or obscurity arises in its use, the particular sense in which it is applied being generally evident by the context; nevertheless it is to be desired that writers on physics could agree upon a nomenclature more definite. The term *caloric* has been

proposed, and to some extent adopted, to express the physical agent to which the effects of heat are due.

410. Of all the various effects of heat, those which are best adapted to indicate and measure temperature are dilatation and contraction. The same body always has the same volume at the same temperature, and always suffers the same change of volume with the same change of temperature.

Since the volume and change of volume admit of the most exact measurement and of the most precise numerical expression, they become the means of submitting the degrees of warmth and cold, or, which is the same, the degrees of temperature, to arithmetical measure and expression.

411. Although all bodies whatever are susceptible of dilatation and contraction by change of temperature, they are not equally convenient for thermoscopic agents. For reasons which will become apparent hereafter, the most available thermoscopic substance for general purposes is mercury.

412. The mercurial thermometer consists of a capillary tube of glass, at one end of which a thin spherical or cylindrical bulb is blown, the bulb and a part of the tube being filled with mercury.

When such an instrument is exposed to an increase of temperature, the glass and mercury will both expand; but the mercury expands 20 times more than the glass, and therefore the mercury must rise in the tube, not having room in the bulb for its increased volume.

The space through which the mercury will rise in the tube by a given increase of temperature will be greater or less according to the proportion which the tube bears to the capacity of the bulb. The smaller the proportion the tube bears to the capacity of the bulb, the greater will be the elevation of the column produced by a given increase of temperature.

Such an instrument, without other appendages or preparation, would merely indicate such changes of temperature in a given place, as would be sufficient to produce visible changes in the elevation of the column of mercury sustained in the tube. To render it useful for the purposes of science and art, and in domestic economy, various precautions are necessary, which have for their object to render the indications of different thermometers comparable with each other, and to supply exact numerical indications of measurement of the changes of temperature.

413. For this purpose it is necessary, in the first instance, that the mercury with which the tube is filled shall be perfectly pure and homogeneous.

In the selection of the tube it is necessary that it be capillary, that is to say, a tube having an extremely small bore, and that the bore should be of uniform magnitude throughout its entire length. The smallness of the bore is essential to the sensibility of the instrument, as already explained; and its uniformity is necessary in order that the same change of volume of the mercury should correspond to the same length of the column in every part of the tube.

The air is expelled from the tube and bulb, and the mercury let fall into them by the process shown in fig. 229., and the open end of the tube is closed by melting the glass with a lamp and blow-pipe, fig. 230.

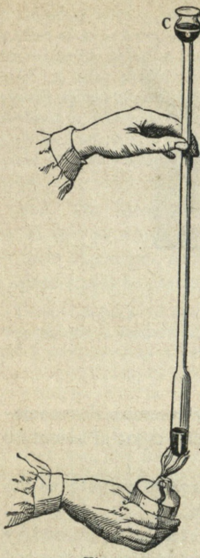

Fig. 229.

414. The *freezing point* is the height at which the mercury stands when exposed to the temperature of melting ice, and the *boiling point* that at which it stands when immersed in boiling water, the height of the barometer being 29·8 inches.

The space between the freezing and boiling point being divided into 180 equal parts, each part is called a *degree*. The same division is continued above the boiling and below the freezing point.

415. The *thermometric scale* commences at the 32nd degree below the freezing point, the commencement being 0, and all degrees below this point being denominated minus and marked —; while those above it are either expressed without a mark or marked +. Thus 40 degrees above 0 are marked +40°, or merely 40°; while 40 degrees below 0 are marked —40°. This is called *Fahrenheit's* scale, and is generally used in England. In France the interval between the freezing and boiling points is divided into

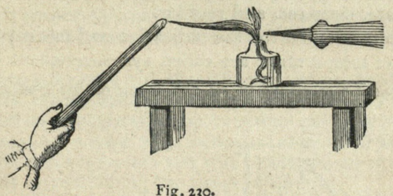
Fig. 230.

100 degrees, and the scale is called the *Centigrade*; and in the north of Europe it is divided into 80 degrees, and the scale is called *Reaumur's*.

416. The most useful form of air thermometer is the differential thermometer shown in *fig*. 231., where A and B are two thin glass bulbs connected by a horizontal tube D E, which contains a drop of mercury, which is moved to the right or the left according as the air in one or the other bulb is at a higher temperature.

Its extreme sensitiveness, in virtue of which it indicates changes

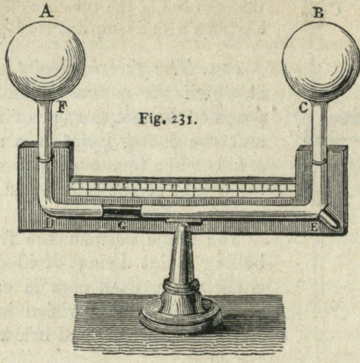

Fig. 231.

of temperature too minute to be observed by common thermometers, renders it extremely valuable as an instrument of scientific research.

By this instrument, changes of temperature so minute as the 6000th part of a degree are rendered sensible.

417. The range of the mercurial thermometer being limited by the boiling point of mercury, higher temperatures are measured by the expansion of solids, whose points of fusion are at a very elevated part of the thermometric scale. The solids which are best adapted for this purpose are the metals. Being good conductors, these are promptly affected by heat, and their indications are immediate, constant, and regular.

Instruments adapted for the indication and measurement of this high range of temperature are called *pyrometers*.

The instrument represented in *fig.* 232. is one of the most simple forms of pyrometer.

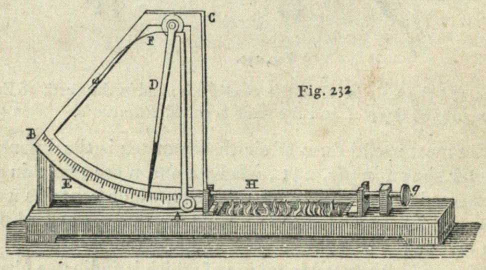

Fig. 232

A rod of metal, H, is in contact at one end with the point of a screw *g*, and at the other with a lever A near its fulcrum. This lever is connected with another so as to form a compound system, such that any motion imparted by the rod to the point on the lever A in contact with it is augmented in a high ratio. A lamp placed under the rod H raises its temperature; and, as it is resisted by the point of the screw *g*, its dilatation must take effect against the lever A, which, acting on the second lever D, will move the index on the graduated arc A B. The ratio of this motion to that of the end of the bar acting on the lever being known, the quantity of dilatation may be calculated.

418. The force with which solid bodies dilate and contract is equal to that which would compress them through a space equal to their dilatation, and to that which would stretch them through a space equal to the amount of their contraction.

Thus, if a pillar of metal one hundred inches in height, being raised in temperature, is augmented in height by a quarter of an inch, the force with which such increase of height is produced is equal to a weight which being placed upon the top of the pillar would compress it so as to diminish its height by a quarter of an inch.

In the same manner, if a rod of metal, one hundred inches in length, be contracted by diminished temperature, so as to render its length a quarter of an inch less, the force with which this contraction takes place is equal to that which being applied to stretch it would cause its length to be increased by a quarter of an inch.

419. In all cases where moulds are constructed for casting objects in metal the moulds must be made larger than the intended magnitude of the object, in order to allow for its contraction in cooling. Thus the moulds for casting cannon balls must always be greater than the calibre of the gun, since the magnitude of the mould will be that of the ball when the metal is incandescent, and therefore greater than when it is cold.

420. Hoops surrounding water-vats, tubs, and barrels, and other vessels composed of staves, and the tires surrounding wheels, are put on in close contact at a high temperature, and, cooling, they contract, and bind together the staves or fellies with greater force than could be conveniently applied by any mechanical means.

421. In all structures composed of metal, or in which metal is used in combination with other materials, such as roofs, conservatories, bridges, railings, pipes for the conveyance of gas or water, rafters for flooring, &c. compensating expedients must be introduced, to allow the free play of the metallic bars in dilating and contracting with the vicissitudes of temperature, to which they are exposed during the change of seasons.

These expedients vary with the way in which the metal is applied, and with the character of the structure. Pipes are generally so joined from place to place as to be capable of sliding one within another, by a telescopic joint. The successive rails which compose a line of railway cannot be placed end to end, but space must be left between their extremities for dilatation.

422. Sheet lead and zinc, both of which metals are very dilatable, when used to cover roofs, where they are especially exposed to vicissitudes of temperature, are liable to blister in hot weather by expansion and to crack in cold weather by contraction, unless expedients are adopted to obviate this: zinc, being much more dilatable than lead, is more liable to these objections.

When ornamental furniture is inlaid with metal without providing for its expansion, the metal, being more dilatable than the wood, is liable, in a small room, to expand and start from its seat.

423. It has been ascertained that the dilatation of all bodies in the gaseous form is perfectly uniform throughout the whole extent of the thermometric scale, the same increments of temperature producing, under the same pressure, equal increments of volume. But, what is still more remarkable, it has been found that all gases whatever, as well as all vapours raised from liquids by heat, are subject to exactly the same quantity of expansion by the same change of temperature.

The increment of volume which any gas or vapour undergoes when, under the same pressure, the temperature is raised one degree, is the 490th part of the volume which it would have if reduced to the temperature of 32°.

The expansion and contraction of air explain a multitude of phenomena which present themselves in the natural world, in domestic economy, and in the arts.

424. In the ventilation and warming of buildings, the entire process, whatever expedients may be adopted, is dependent upon this principle. When a fire is lighted in an open stove to warm a room, the smoke and the gaseous products of combustion, ascending the chimney, soon fill the flue with a column of air so expanded by heat as to be lighter, bulk for bulk, than a similar column of atmospheric air. Such a column, therefore, will have a buoyancy proportional to its relative lightness. This upward tendency constitutes the draft of the chimney; and this draft will accordingly be strong and effective in just the same proportion as the column of air in the chimney is kept warm. When the fire is first lighted, the chimney being filled with cold air, there is no draft, and, consequently, the flame and smoke often issue into the room. According as the column of air in the chimney becomes gradually warm, the draft is produced and increased. The draft is sometimes stimulated by holding burning fuel for some time in the flue, so as to warm the lower strata of air in it.

But the most effectual method of stimulating the draft when the fire is lighted is by what is called a *blower*, which is a sheet of iron that stops up the space above the grate bars, and prevents any air from entering the chimney except that which passes through the fuel, and produces the combustion. This soon causes the column of air in the chimney to become heated, and a draft of considerable force is speedily produced through the fire.

425. An open chimney differs from a close stove, inasmuch as the former serves the double purpose of warming and ventilating the room, whereas the latter only warms, and can scarcely be said to ventilate. In a close stove, no air passes through the room to the flue of the chimney, except that which passes through the fuel, and that is necessarily limited in quantity by the rate of combustion maintained in the stove. In an open fire-place, on the other hand, two independent currents of air pass into the flue: one is that which passes through the fuel and maintains the combustion, and the other, which is far more considerable in quantity, is that which passes through the opening of the fire-place above the grate.

The temperature of the column in the flue is due entirely to the former, and the activity of the combustion will be determined by the relative magnitudes of the grate and the space above it; these two magnitudes representing the proportion in which the open stove serves the two purposes of warming and ventilation, the grate representing the function of warming, and the space above it the function of ventilating. Even when there is no fire lighted in the grate, the column of air in the chimney is in general at a higher temperature than the external air, and a current will therefore in such case be established up the chimney, so that the fire-place will still serve, even in the absence of fire, the purposes of ventilation. In very warm weather, however, when the external air is at a higher temperature than the air within the building, the effects are reversed; and the air in the chimney being cooled, and therefore heavier than the external air, a downward current is established, which produces in the room the odour of soot. To prevent this, a trap or valve is usually provided in it, which can be closed at pleasure, so as to intercept the current. It should be observed, however, that this trap should only be closed when a downward current is established; since, at other times, even in the absence of fire, the ventilation of the apartment is maintained.

426. In all apparatus adapted to warm buildings, the fact that warm air is more expanded, and therefore lighter, bulk for bulk, than cool air, requires to be attended to. It is usual to admit the warm air through apertures placed in the lower parts of a room, because it will ascend by its buoyancy and mix with the colder air, whereas if it were admitted by apertures near the ceiling it would form strata in the upper part of the room, and would escape at any apertures which might be found there. But if there be means of escape only in the lower part of the room, then the strata of warm air let in above will gradually press down upon the cool air below and force it out through the chimney, doors, windows, or other apertures.

In general, the air contained in an apartment collects in strata arranged according to its temperature, the hotter air collecting near the ceiling, and the strata decreasing in temperature downwards. Thermometers placed at different heights between the floor and the ceiling would accordingly show different temperatures. The difference of these temperatures is sometimes so considerable, that flies will continue to live in one stratum which would perish in another.

If the door of an apartment be open it will be found that two currents are established through it, the lower current flowing inwards and the upper outwards. If a candle be held in the doorway near the floor, it will be found that the flame will be blown inwards; but if it be raised nearly to the top of the doorway, the flame will be blown outwards. The warm air in this case flows out at the top, while the cold air flows in at the bottom.

427. Although open fire-places placed in dwelling-rooms are agreeable to the eye, and healthful so far as they generally ensure an efficient ventilation, they are extremely costly, an enormous proportion of the heat developed by the fuel passing up the chimney without in any way contributing to the warmth of the room. In public buildings and other places, where all the apartments can be warmed by a common apparatus, the object is attained with much greater economy. Two methods are practised; one by currents of heated air, and the other by currents of heated water.

The method of warming buildings by currents of heated air will be easily understood by reference to *fig.* 233., where E is a furnace constructed in the basement of the building, over which there is a metal pipe carried, following a winding course. The flame and heated air, passing round this pipe, raise the air in it to a high temperature. A current of cold air enters at the end B of the pipe which is outside the building, and after following the course of the pipe, issues at A into the apartment to be heated. Meanwhile, the smoke and heated air which has warmed the air-pipe escapes up the chimney.

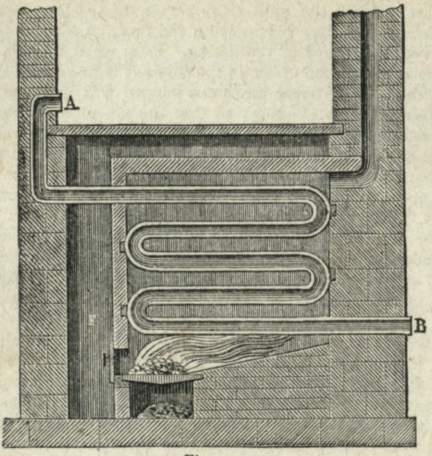

Fig. 233.

It is most important to observe that in all cases where these "*calorifères*," as they are called, are used, some efficient means of ventilation should be provided to play the part of the open fire-place.

The expansion of air by heat and its contraction by cold may be made manifest by a variety of simple and easily executed experiments. If a common drinking glass be inverted and held over the flame of a lamp or candle for some time, it will be filled with air heated by the flame; if it be then suddenly plunged with its mouth downwards in water, the water will be found to rise in the glass to a height above the level of the water outside the glass. The cause of this is, that the air which fills the glass, having been previously rarefied by heat and afterwards cooled, when removed from the lamp, is contracted so as to fill a less space than the capacity of the glass which it filled when heated previous to immersion.

This experiment may be rendered still more striking by using a glass bulb blown at the end of a tube, like a thermometric tube, instead of a glass. Let such a bulb be held for some minutes over the flame of a spirit-lamp. The air which fills it will become highly expanded and rarefied by the heat. Let the open end of the tube be then plunged in water, the bulb being presented upwards. After some time, when the tube has cooled and the air within it contracted, the water will rise in the tube, and will nearly fill the bulb, the portion of the bulb not filled being the space within which the air previously heated had been contracted by cooling.

428. The liquid state is one of transition between the solid and the vaporous states. Solids by heat are converted into liquids, and liquids into vapours.

The liquid state, therefore, is maintained between two limits of temperature; a lower limit, at which the liquid would solidify, and a higher limit, at which it would vaporise. In different liquids these limits are separated by a greater or less range of temperature. In some, alcohol for example, the point of solidification stands at a very low temperature on the scale; while in others, as in some of the oils, the point of vaporisation is placed at a very high limit. In others, as in mercury, these points are widely separated, the vaporising point being at a very high, and the freezing point at a very low temperature.

429. It is found in general that the rate of dilatation of liquids is not uniform, like that of solids and gases, and that it not only increases as the temperature is elevated, but is subject to certain irregularities as it approaches the points at which the liquid would pass, on the one hand, into the solid, and, on the other, into the vaporous state.

Water contracts until its temperature falls to 38°·8, but from that until it descends to the freezing point it expands; and this expansion undergoes a great increase in the water passing from the liquid to the solid state.

Water is, therefore, in its state of greatest density when its temperature is 38°·8.

430. It is found by experiment that when ice is in process of melting, it absorbs heat without suffering any increase of temperature. The quantity of heat thus absorbed, is such as would suffice to raise the same weight of water from 32° to 174°·65. Thus it appears, that as much heat is required to melt a pound of ice, as would raise a pound of water about 143°.

In the same manner by a reverse process, water in freezing parts with as much heat as would raise it 143°.

This is called the *latent heat of liquefaction.* All other solids absorb heat in melting, and give it out in congealing, but the quantity varies.

431. The great quantity of heat absorbed by ice when it melts, and given out by water when it freezes, subserves to the most important uses in the economy of nature. It is from this cause that the ocean, seas, and other large natural collections of water are most powerful agents in equalising the temperature of the inhabited parts of the globe. In the colder regions, every ton of water converted into ice gives out and diffuses in the surrounding region as much heat as would raise a ton of liquid water from 32° to 174°·65; and, on the other hand, when a rise of temperature takes place, the thawing of the ice absorbs a like quantity of heat: thus, in the one case, supplying heat to the atmosphere when the temperature falls; and, in the other, absorbing heat from it when the temperature rises. Hence we see why the variations in climate are less on the sea-coasts and on islands, than in the interior of large continents.

The temperature of the air under the line does not vary much more than 4°, and that of the water varies not more than 1°.

432. It may be taken as a physical law of high generality, that a solid cannot pass into the liquid state without absorbing and rendering latent a certain quantity of heat. This heat may be, and often is, supplied from some other body in contact with that which is liquefied. But if no such external supply of heat be present, and if, nevertheless, any physical agency cause the liquefaction to take place, the body thus liquefied will actually absorb its own sensible heat. While it is liquefied, it will, therefore, fall in temperature to that extent which is necessary to supply its latent heat of fluidity at the expense of its sensible heat.

To render this more clear, let us imagine a pound of ice at the temperature of 32° to be mixed with a pound of liquid having the temperature of —103°, and let this liquid be supposed to have the property of dissolving the ice. When the liquefaction is completed, the temperature of the mixture will be —103°. Now the liquid, which is here supposed to be the solvent, neither imparts heat to the ice nor abstracts heat from it. The ice, therefore, now liquefied, contains exactly as much heat as it contained before liquefaction, and no more. But, to become liquid, it was necessary that 142°·65 of heat should be absorbed by it, and become latent in it. This 142°·65 has therefore been transferred from the sensible to the latent state in the ice itself.

This principle has been applied extensively in scientific researches and in the arts for the production of artificial cold, the compounds thus made being called *freezing mixtures.*

The substances which may be used to produce freezing mixtures on this principle are very various.

If equal weights of snow and common salt at 32° be mixed, they will liquefy, and the temperature will fall to —9°. If two pounds of muriate of lime and one pound of snow be separately reduced to —9° in this liquid and then mixed, they will liquefy, and the temperature will fall to —74°.

If four pounds of snow and five pounds of sulphuric acid be reduced separately to —74° in this last mixture and then mixed, they will liquefy, and the temperature will fall to —90°.

433. Of all liquids, that of which the vaporisation is of the greatest physical importance, and consequently that which has been the subject of the most extensive system of observations, is water.

It is found that, in all cases, water passing into the vaporous state undergoes an enormous enlargement of volume, and that this enlargement increases as the temperature at which the evaporation takes place is diminished. Thus, if the temperature be 212°, a cubic inch of water swells into 1696 cubic inches; and if the temperature be 77°, it swells into 23090 cubic inches of vapour.

434. There is no temperature, however low, at which water will not evaporate. Thus, a piece of ice at the temperature of —4° (that is, 36° below the freezing point) produces a vapour whose

pressure is represented by a column of mercury of a twentieth of an inch.

When a liquid expands into vapour, it exerts a certain mechanical force, the amount of which depends on the pressure of the vapour, and the increased volume which the liquid undergoes in evaporation. Thus, if a cubic inch of a liquid swells by evaporation into 2000 cubic inches of vapour, having a pressure of 10 lbs. per square inch, it is easy to show that a mechanical force is developed in such evaporation which is equivalent to 20000 lbs. raised through one inch. For, if we imagine a cubic inch of the liquid confined in a tube, the bore of which measures a square inch, it will, when evaporated, fill 2000 inches of such tube, and, in swelling into that volume, will exert a pressure of 10 lbs., so that it would in fact raise a weight of 10 lbs. through that height. Now 10 lbs. raised through the height of 2000 inches, is equivalent to 20000 lbs. raised through the height of one inch.

It may be considered as certain that all that class of bodies which are denominated permanent gases, are the super-heated vapours of bodies which, under other thermal conditions, would be found in the liquid or solid state. It is easy to conceive a thermal condition of the globe, which would render it impossible that water should exist save in the state of vapour. This would be the case, for example, if the temperature of the atmosphere were 212° with its present pressure. A lower temperature, with the same pressure, would convert alcohol and ether into permanent gases.

435. The numerous experiments by which many of the gases hitherto regarded as permanent have been condensed and reduced to the liquid, and, in some cases, to the solid state, have further confirmed the inferences based on these physical analogies. The principle on which these experiments have in general been founded is, that if, by any means, the heat which a super-heated vapour has received after having assumed the form of vapour can be taken from it, the condensation of a part of it must necessarily attend any further loss of heat, since, by what has been explained, it will be apparent that no heat will remain in it except what is essential to its maintenance in the vaporous state.

The gas which it is desired to condense is first submitted to severe compression, by which its temperature is raised either by diminishing its specific heat or by developing heat that was previously latent in it. The compressed gas is at the same time surrounded by some medium of the most extreme cold; so that, as fast as heat is developed by compression, it is absorbed by the surrounding medium.

When, by such means, all the heat by which the gas has been surcharged has been abstracted, and when no heat remains save what is essential to the maintenance of the elastic state, the gas is in a thermal condition analogous to that of vapour which has been directly raised by heat from a liquid, and which has not received any further supply of heat from any other source It follows, therefore, that any further abstraction of heat must cause the condensation of a corresponding portion of the gas.

The following gases, being kept at the constant temperature of 32° by depriving them of heat as fast as their temperature was raised by compression, have been reduced to the liquid state. The pressures necessary to accomplish this are here indicated: —

Names of Gases condensed.	Pressure under which Condensation took place.
	Atmospheres.
Sulphurous acid - - - -	1·5
Cyanogen gas - - - -	2·3
Hydriodic acid - - - -	4·0
Ammoniacal gas - - - -	4·4
Hydrochloric acid - - - -	8·0
Protoxide of azote - - - -	37·0
Carbonic acid - - - -	39·0

If these substances be regarded as liquids, the above pressures would be those under which they would vaporise at 32°. If they be regarded as vapours, they are the pressures under which they would be condensed at 32°.

436. When a liquid passes into the state of vapour, it absorbs a certain quantity of heat without being rendered hotter, and when the vapour is reconverted into the liquid, it parts with an equal quantity of heat. This is called the *latent heat of vapour*.

When water is vaporised, it absorbs as much heat as would raise 6½ times its own weight of water from the freezing to the boiling point.

437. *Distillation* depends upon the successive evaporation and condensation of liquids, and is used for the purpose of separating liquids from impurities which they may hold in solution.

The process by which water is first converted into vapour and then restored to the state of water is called distillation, from a Latin word DISTILLATIO, which signifies "falling in drops." The conversion of the vapour into liquid in the condenser usually proceeds so slowly that the liquid falls from the spout of the condenser, not in a continuous stream, but in a succession of drops.

In the industrial arts, and in chemical laboratories, where water absolutely pure is needed in considerable quantities, its distillation is conducted in an apparatus which is represented in *fig*. 234.

This distilling apparatus, or alembic, consists of a copper boiler, A, fixed in a brick furnace, having a dome-formed cover, B, adapted to it, from which a bent tube, *b c d*, proceeds, and is connected with a spiral tube called a *worm*. This worm is enclosed in a large cylindrical cistern, *p q j r*, constructed in metal, and which is kept constantly filled with cold water. The lowest part of the worm passes out of this cistern near its bottom, and terminates at *a*, over the mouth of a jar, *c*, intended to receive the distilled water. An opening, *t*, having a steam-tight stopper, is provided in the boiler, through which the water to be distilled is introduced into it.

The vapour issuing from the boiler through the tube, *b c d*, passes into the worm, being first received by the vessel, O, where the condensation begins.

Passing next through the coils of the worm, it is exposed to the contact of its cold surface, and is entirely condensed and reduced to the liquid state before it arrives at the lower extremity, *a*, from which it trickles in drops into the jar, *c*.

The heat disengaged from the vapour in the process of condensation being

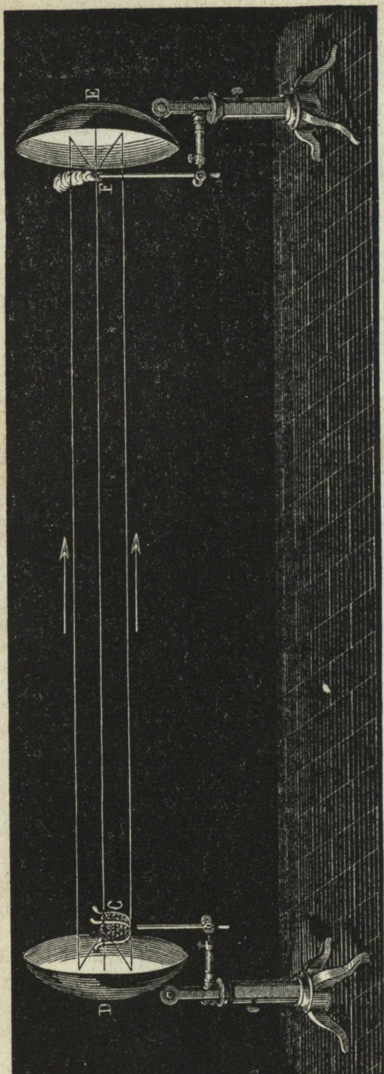

Fig. 236

with boiling water, the thermometer will instantly show an increase of temperature caused by the heat radiated from the surface of the canister and collected into a focus upon the ball by the reflector.

446. The general principles regulating the radiation, absorption, reflection, and transmission of heat, which have been here stated, serve to explain and illustrate various experimental facts and natural phenomena, as will appear from what follows: —

If two concave parabolic reflectors, shown in *fig.* 236., are so placed that their axes shall be in the same direction their concavities being presented one to the other any radiator of heat placed in the focus of either will produce a corresponding effect upon a thermometer placed in the focus of the other, the rays of heat issuing from the radiating body being twice reflected and collected in the focus of the second reflector.

447. Vessels intended to hold liquids at a higher temperature than that of the surrounding medium should be constructed of materials which are bad radiators. Thus tea-urns, tea-pots, &c., are best adapted for their purpose when made of polished metal and worst when of

black porcelain. A tea-kettle keeps water hot more effectually if clean and polished, than if covered with the black of soot and smoke. Polished fire-irons remain longer before a hot fire without being heated than rough unpolished ones.

448. A polished stove is a bad radiator; one with a rough and blackened surface a good radiator. The latter is therefore better adapted for warming an apartment than the former.

449. The helmet and cuirass worn by cavalry is a cooler dress than might be imagined, the polished metal being a good reflector of heat, and throwing off the solar rays.

450. When the external air, which generally happens, is at a lower temperature than the air included in the room, it will be observed that a deposition of moisture will be formed upon the inner surface of the panes of glass in the windows. This is produced by the vapour suspended in the atmosphere of the room being condensed by the cold surface of the glass. If the external air in this case be at a temperature below 32°, the deposition on the inner surface of the glass will be congealed, and a rough coating of ice will be exhibited upon it.

451. A clear unclouded sky in the absence of the sun radiates but little heat towards the earth; consequently, if good radiators be exposed to such an aspect, they must suffer a fall of temperature, since they lose more by radiation than they receive.

Objects which are good radiators, exposed to a clear sky at night, will become colder than the surrounding atmosphere, and will consequently condense the water suspended in the air around them; while objects which are bad radiators will not do this. Grass, foliage, and other products of vegetation are in general good radiators. The vegetation, therefore, which covers the surface of the ground in an open country on a clear night will receive a deposition of moisture from the atmosphere; while the objects which are less perfect radiators, such as earth, stones, &c., do not in general receive such depositions. In the close and sheltered streets of cities the deposition of dew is rarely observed, because there the objects are exposed to reciprocal radiation, and an interchange of heat takes place which maintains their temperature.

The effect of the radiation of foliage is strikingly manifested by the following example:—Of two thermometers, one laid among leaves and grass, and the other suspended at some height above them, the latter will be observed to fall at night many degrees below the former.

452. In a cloudy night dew is not deposited, because in this case, although vegetation radiates as perfectly as before, the clouds also radiate, and an interchange of heat takes place between them and the surface of the earth, by which the fall of temperature producing dew is prevented.

453. Artificial ice is sometimes produced in hot climates by the following process:—A position is selected, not exposed to the radiation of surrounding objects, and a quantity of dry straw is spread on the ground, on which pans of porous earthenware are disposed in which the water to be cooled is placed. The water radiates heat to the firmament, and receives no heat in return. The straw upon which the vessels are placed, being a bad conductor, intercepts the heat, which would otherwise be imparted to the water in the vessels from the earth. The porous nature of

the pans also allowing a portion of the water to penetrate them, produces a rapid evaporation, by which a considerable quantity of the heat of the water is carried off in a latent state by the vapour. Heat is thus dismissed at once by evaporation and radiation, and the temperature of the water in the pans is diminished until it attains the freezing point. In the morning the water is found frozen, and is collected and placed in cellars surrounded with straw or other bad conductors, which prevents its liquefaction.

454. When the quantity of heat suddenly developed by the chemical combination of two bodies renders the compound luminous, the bodies are said to burn, and the phenomenon is called *combustion*. If the product of the combination be solid it is called *fire*; if gaseous, *flame*.

Flame, therefore, is gas rendered *white hot* by the excessive heat developed in the combination which produces it.

455. It happens that, among the infinite variety of substances whose combination is productive of this class of phenomena, one of the two combining bodies is almost invariably oxygen gas. A few other substances, such as chlorine, bromine, and iodine, produce similar effects; but in all ordinary cases of combustion, and universally where that effect is resorted to as a source of artificial heat, one of the combining substances is oxygen gas. On this account this gas has been called a *supporter of combustion*.

456. The substances which, combining with it, produce the phenomenon of combustion, are called *combustibles*. The class of combustible substances which are commonly used for the production of artificial heat is called *fuel*. Such, for example, are pit coal, charcoal, and wood.

Another class of combustibles is used for the production of artificial light: such, for example, are oil, wax, and the gas extracted from certain sorts of pit coal, from oil, and from certain sorts of wood, such as the pitch pine. The principal constituents of all these combustibles, whether used for the production of heat or light, are those denominated by chemists *carbon* and *hydrogen*.

457. Carbon is the name given to charcoal when it is absolutely pure, which it never is as it is obtained by the ordinary industrial processes. It is in that state combined with various heterogeneous and incombustible substances. In the laboratories of chemists it is separated from these, and obtained in a state of perfect purity, being there distinguished from the charcoal of commerce by the name *carbon*.

Carbon, having never been resolved by any chemical agent into other constituents, is classed in chemistry as a simple and elementary body, which enters largely into the composition of a numerous class of bodies which are found in nature, or produced in the processes of industry, the sciences, and the arts.

458. A quantity of charcoal being placed in a furnace through which a draught of air is maintained, if a part of it be heated to redness, the entire mass will soon become incandescent, and will emit a reddish light, which will be whiter as the air is passed through it more briskly, and will emit considerable heat. The charcoal will gradually decrease in quantity, and at length will disappear altogether from the furnace, under which a small portion of ashes consisting of incombustible matter will remain. If the charcoal had been pure — that is, if it had been carbon — it would have altogether disappeared, no ash whatever remaining.

459. This phenomenon is an example of combustion. The heat and light developed during the process here described are commonly called fire.

To comprehend what takes place in this process, we must consider that, as the air passes through the charcoal, the oxygen gas, which forms one fifth part of it, enters into combination with the pure carbon. A compound is thus formed consisting of carbon and oxygen. The formation of this compound is attended with so great a production of heat, that not only the compound itself, but the charcoal, from which it is evolved, is raised to a very elevated temperature.

The compound thus produced is a gas called carbonic acid.

The air which enters the furnace being a mixture of azote and oxygen, that which rises from it after the combustion has been produced is a mixture of azote and carbonic acid; the azote having passed through the furnace without suffering other change than an increase of temperature, while the oxygen has been converted into highly heated carbonic acid.

460. *Hydrogen*, like carbon, is a simple substance; and also, like carbon, enters largely into the composition of a numerous class of bodies. Hydrogen combines with oxygen in the proportion of 1 part by weight of the former to 8 of the latter to form water, and if the combination be formed in a pure or nearly pure atmosphere of the gases, it is instantaneous, and accompanied by an explosion. If, however, the combination take place, as it may, in common air, the phenomena will be very different.

If pure hydrogen, compressed in a bladder or other reservoir, be allowed to issue from a small aperture, a light applied to it will cause it to be inflamed. It burns tranquilly without explosion, producing a pale yellowish flame and very feeble light, but intense heat. This is the effect attending the gradual and continual combination of the hydrogen, as it escapes from the aperture, with the oxygen of the surrounding air.

461. The combustion of carbon differs from that of hydrogen in this, that the former takes place without the production of *flame*. The charcoal being heated to redness, and still in the solid form, enters directly into combination with the oxygen of the surrounding air, and the carbonic acid which is formed, being a gas which is not luminous nor visible, the carbon disappears. But in the case of hydrogen, the heat produced by the combustion is so intense as to render the gas itself luminous, just as intense heat

will render a mass of iron red hot or white hot. When gas becomes thus luminous, it is called *flame*. Flame, therefore, must be understood to be nothing more than matter in the aeriform, gaseous, or vaporous state, rendered so intensely hot as to become incandescent, and to emit light, just as would a bar of iron taken from a furnace.

462. The species of combustible used as fuel with which we are most familiar in this country is *pit coal*.

This mineral, exclusive of some extraneous and incombustible ingredients which it contains in very small proportions, consists of carbon and carburetted hydrogen. The proportion of carbon varies in different sorts of coal from 80 to 90 per cent., the hydrogen varying from 3 to 6 per cent., and the remainder consisting of oxygen and azote. In the heavy coal of Wales, called anthracite, the proportion of carbon is above 90 per cent., while that of the hydrogenous gases is only 3 or 4 per cent. In the bituminous coal of Northumberland the proportion of carbon is about 87 per cent., and that of hydrogen from 5 to 6 per cent.

463. When a fire composed of such fuel is properly kindled and supplied with a draught of air necessary to sustain the combustion, the carbon will continue to combine with its proper proportion of oxygen, producing the corresponding quantity of heated carbonic acid, and rendering the solid part of the fuel red and luminous; and the hydrogenous gases will at the same time combine with their respective proportions of oxygen, producing carbonic acid and watery vapour, and rendering the gases as they issue from the fuel luminous, or, what is the same, converting them into flame.

The flame will be faintly luminous and bluish if any part of the gases be pure hydrogen; it will be yellowish and a little more luminous if they be light carburetted hydrogen; and it will be very white and very luminous if they be heavy carburetted hydrogen.

Thus all the phenomena exhibited by a common coal fire, — the red unflaming fuel, — the faint blue flames occasionally seen, — and, in fine, the white brilliant flame which most commonly issues from the fissures of the coal, are severally explained and accounted for.

464. Wood is a combustible generally used for the production of artificial heat in countries where coal is not so cheap and abundant as in England. This fuel, like coal, consists principally of carbon and hydrogen in various proportions, according to the sort of wood. All kinds of wood contain also a proportion of oxygen, as a constituent, much greater than is found in coal.

Wood, when green, contains a considerable proportion of water. In the combustion of such wood a large proportion of the heat developed is absorbed in the evaporation of this water, and is, therefore, lost for heating purposes. Wood used as fuel should, therefore, be kept until this water, or the chief part of it, has been evaporated. For the same reason, wood kept for fuel should be as little exposed to moisture or damp as possible.

465. All fatty, oily, and waxy substances are combustible, whether in the liquid or solid state. They consist of the same constituents as coal and wood, but combined somewhat differently and in different proportions. Most substances of this class, burning with a flame of more or less brilliancy, are used for the purposes of artificial illumination.

Whale, sperm, olive, and cocoa-nut oils, wax, spermaceti, and tallow are examples of this class of combustibles.

CHAP. XIV.

MAGNETISM.

466. Certain ferruginous mineral ores are found in various countries, which being brought into proximity with iron manifest an attraction for it. These are called *natural magnets*, a term derived from *Magnesia*, a city of Lydia, in Asia Minor, where the Greeks first discovered and observed the properties of these minerals.

The natural magnet is also called the *loadstone*, or more properly *lodestone*, or *leadstone*, a name indicative of the guiding property of the magnet, just as the pole star was called the *lodestar*.

The natural magnet is a compound consisting of one equivalent of the protoxide and one of the sesquioxide of iron. This mineral abounds in Sweden and Norway, where it is worked for the production of the iron of commerce, yielding the best quality of that metal known.

467. The same property may be imparted to any mass of iron, having any desired magnitude or form, by processes which will be explained hereafter. Such pieces of iron having thus acquired these properties are called *artificial magnets*; and it is with these chiefly that scientific experiments are made, since they can be produced in unlimited quantity of any desired form and magnitude, and having the magnetic virtue, within practical limits, in any desired degree.

468. This attractive power is not diffused uniformly over every part of the surface. It is found to exist in some parts with much greater force than in others, and on a magnet a certain line is

found where it disappears. This line divides the magnet into two parts or regions, in which the attractive power prevails in varying degrees, its energy augmenting with the distance from the neutral line just mentioned.

469. This neutral line may be called the *equator* of the magnet. The two regions of attraction separated by the equator are called the *poles* of the magnet.

Sometimes this term *pole* is applied to two points, which are the centres of all the magnetic attractions, in the same manner as the centre of gravity is the centre of all the gravitating forces which act upon the particles of a body.

470. The neutral line and the varying attraction of the parts of the surface of the magnet which it separates may be manifested experimentally as follows. Let a magnet, whether natural or artificial, be rolled in a mass of fine iron filings. They will adhere to it, and will collect in two tufts on its surface, separated by a space upon which no filings will appear.

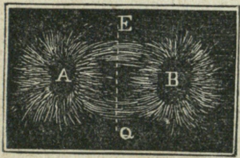

Fig. 237.

This effect, as exhibited by a natural magnet of rough and irregular form, is represented in *fig.* 237.; and as exhibited by an artificial magnet in the form of a regular rod or cylinder whose length is considerable as compared with its thickness, is represented in *fig.* 238.; the equator being represented by E Q, and the poles by A and B.

If two magnets, so placed as to have free motion, be presented to each other, they will exhibit either mutual attraction or mutual repulsion, according to the parts of their surfaces which are brought into proximity. Let E and E′, *fig.* 239., be two magnets, their poles being respectively A B and A′ B′. Let the two poles of each of these be successively presented to the same pole of a third magnet. It will be found that one will be attracted and the other repelled. Thus, the poles A and A′ will be both attracted, and the poles B and B′ will be both repelled by the pole of the third magnet, to which they are successively presented.

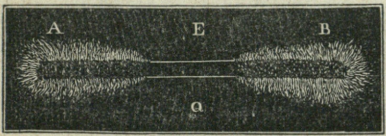

Fig. 238.

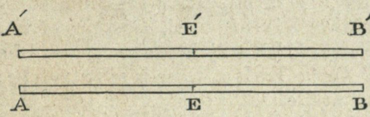

Fig. 239.

The poles A and A′, which are both attracted, and the poles B and B′ which are both repelled by the same pole of a third magnet, are said to be *like poles;* and the poles A and B′, and B and A′, one of which is attracted and the other repelled by the same pole of a third magnet, are said to be *unlike poles.*

Thus the two poles of the same magnet are always unlike poles, since one is always attracted, and the other repelled, by the same pole of any magnet to which they are successively presented.

If two like poles of two magnets, such as A and A′ or B and B′, be presented to each other, they will be mutually repelled; and if two unlike poles, as A and B′ or B and A′, be presented to each other, they will be mutually attracted.

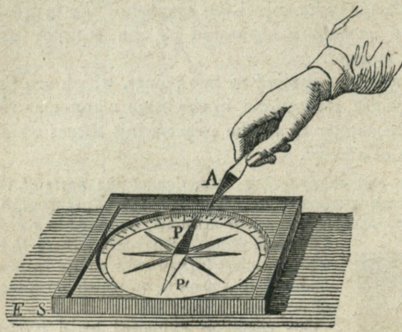

Fig. 240.

Thus it is a general law of magnetic force, that like poles mutually repel and unlike poles mutually attract.

If the pole A of a magnet be presented first to P and then to P′, it will repel one and attract the other, *fig.* 240.

If a key C (*fig.* 241.) be suspended by the pole B, it will fall from it when the unlike pole A of another magnet is applied to it, the magnetism of the two unlike poles neutralising each other.

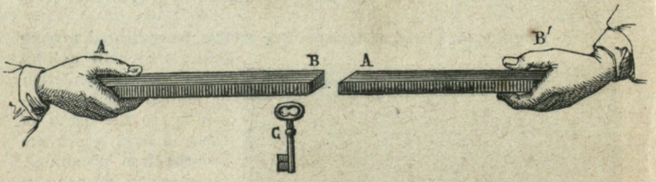

Fig. 241.

471. These phenomena, and others which will presently be stated, have been explained by different suppositions, one of which assumes that all bodies susceptible of magnetism are pervaded by a subtle imponderable fluid, which is compound, consisting of two constituents called, for reasons which will hereafter appear, the *austral fluid* and the *boreal fluid.* Each of these is self-repulsive; but they are reciprocally attractive, that is to say, the austral fluid repels the austral, and the boreal the boreal; but the austral and boreal fluids reciprocally attract.

When a body is magnetic, the fluid which pervades it is decomposed, the austral being directed towards one side of the equator, and the boreal towards the other. That side of the equator towards which the austral fluid is directed is the *austral*, and that towards which the boreal fluid is directed is the *boreal pole* of the magnet.

If the austral poles of the two magnets be presented to each other, they will mutually repel, in consequence of the mutual repulsion of the fluids which are directed towards them; and the same effect will take place if the boreal poles be presented to each other. If the austral pole of the one magnet be presented to the boreal pole of another, mutual attraction will take place, because the austral and boreal fluids, though separately self-repulsive, are reciprocally attractive.

It is in this manner that the hypothesis of two self-repulsive and mutually attractive fluids supplies an explanation of the general magnetic law, that like poles repel and unlike poles attract. It must be observed that the attraction and repulsion in this hypothesis are imputed, not to the matter composing the magnetic body, but to the hypothetical fluids by which this matter is supposed to be pervaded.

472. The force with which the opposite fluids are combined in bodies susceptible of magnetism varies. In some the conductor is feeble, so that they are easily decomposed, and the body consequently easily magnetised. In others they are more strongly combined, resisting decomposition, and rendering magnetism more difficult.

The facility with which, after decomposition, they are recombined, so as to restore the body to its natural or unmagnetised state, is always proportionate to that with which they are decomposed.

This force, which resists decomposition and recomposition with more or less intensity, is called the *coercive force*. It has great intensity in highly tempered steel, which consequently, when once magnetised, retains its magnetism; and it is scarcely sensible in soft iron, which, when magnetism is momentarily imparted to it, loses the virtue almost instantaneously.

473. The only substances in which the magnetic fluid has been decomposed, and which are therefore susceptible of magnetism, are iron, nickel, cobalt, chromium, and manganese, the first being that in which the magnetic property is manifested by the most striking phenomena.

474. If the extremity of a bar of soft iron be presented to one of the poles of a magnet, this bar will itself become immediately magnetic. It will manifest a neutral line and two poles, that pole which is in contact with the

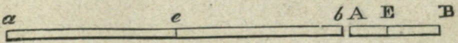

Fig. 242.

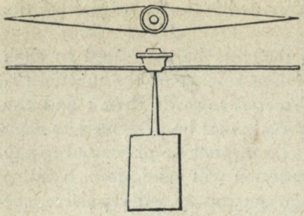

Fig. 243.

magnet being of a contrary name to the pole which it touches. Thus, if A B, *fig.* 242., be the bar of soft iron which is brought in contact with the boreal pole *b* of the magnet *a b*, then A will be the austral and B the boreal pole of the bar of soft iron thus rendered magnetic by contact, and E will be its equator, which, however, will not be in the middle of the bar, but nearer to the point of contact. These effects are thus explained by the hypothesis of two fluids.

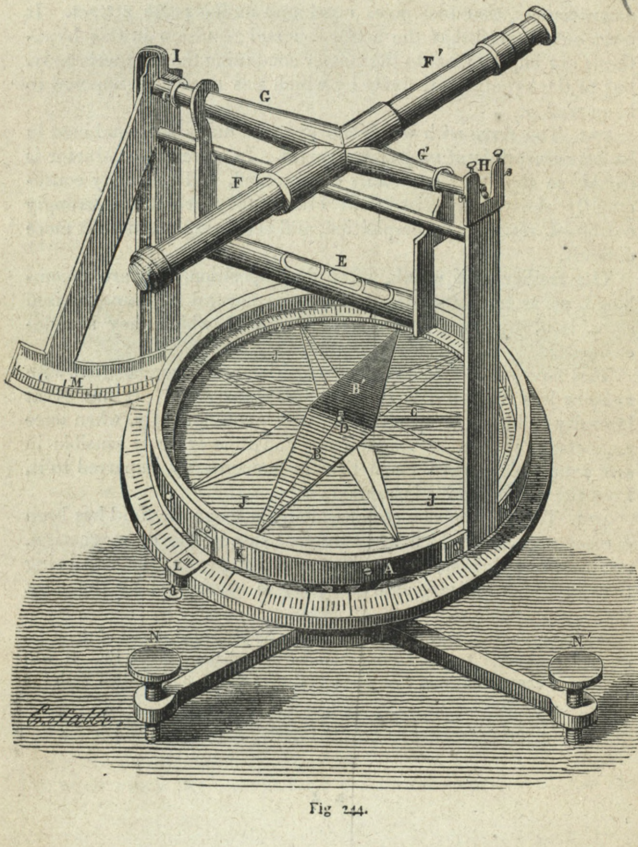

Fig. 244.

The attraction of the boreal pole of the magnet *a b* acting upon the magnetic fluid which pervades the bar A B, decomposes it, attracting the austral fluid towards the point of contact A, and repelling the boreal fluid towards B. The austral fluid accordingly predominates at the end A, and the boreal at the end B, a neutral line or equator E separating them.

475. *Induction* is the name given to this process, by which magnetism is developed by magnetic action at a distance.

476. A magnetic needle generally receives the form of a lozenge, as represented in *fig.* 243., having a conical cup of agate at its centre, which is supported upon a pivot in such a manner as

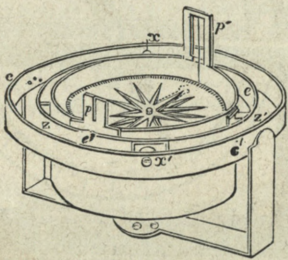

Fig. 245.

that the needle is free to turn in a horizontal plane, round the pivot as a centre. In this case the weight of the needle must be so regulated as to be in equilibrium on the pivot.

Bar magnets are pieces of steel in the form of cylinders or prisms, whose length is considerable compared with their depth or thickness. In producing such magnets certain processes are necessary, which will be explained hereafter.

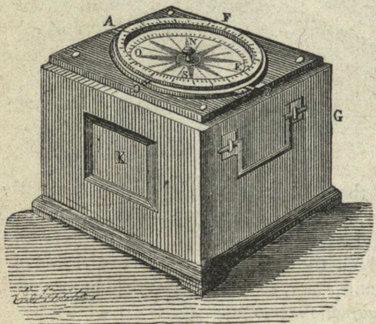

Fig. 246.

477. *Compound magnets* consist of several bar magnets, equal and similar in magnitude, being placed one upon the other with their corresponding poles together.

478. When a magnetic needle is freely suspended, it will always take a direction nearly north and south, the boreal pole being directed to the south and the austral to the north. This is explained by the supposition that the earth itself

is a magnet whose boreal pole is in the northern, and austral in the southern hemisphere. The boreal pole of the magnetic needle is therefore attracted towards the south, and the austral towards the north.

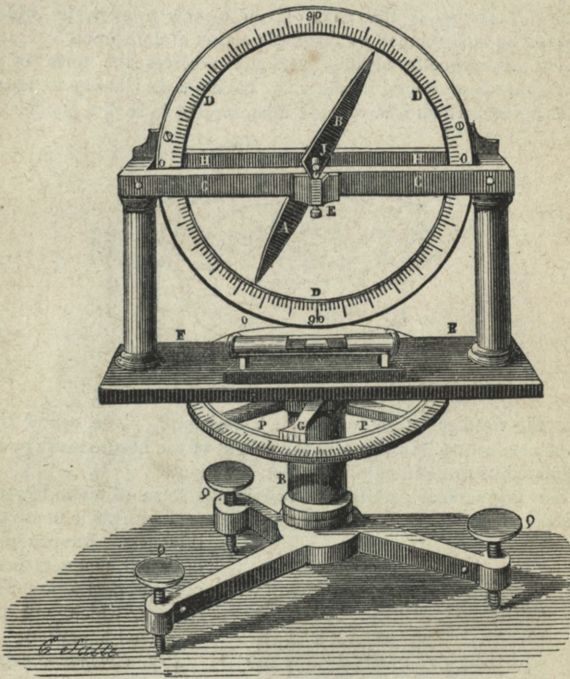

Fig. 247.

479. The direction of the needle is nearly, but not exactly north and south. Its deviation from the true north and south is called the *declination* or *variation* of the needle.

480. The points to which the needle is actually directed are called the *magnetic north* and *south*, and the vertical plane through the needle is called the *magnetic meridian*.

481. A needle suspended on a vertical pivot showing the direction of the magnetic meridian, is called an *azimuth compass*.

For scientific purposes this instrument is mounted, as shown in *fig*. 244.

482. For the purposes of navigation it is mounted on *gimbals*,

as shown in *fig.* 245., and is called the mariner's compass. It is usually inclosed in a box, as shown in *fig.* 246.

483. The centres of the earth's polarity being at certain points

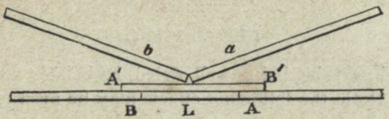

Fig. 248.

within each hemisphere, there is a tendency to *attract* the austral pole of a needle *downwards*, and to *repel* the boreal pole *upwards* in the northern hemisphere. The contrary effect is produced in the southern hemisphere. A needle suspended on a horizontal axis turning in a vertical plane, and called the *dipping needle*,

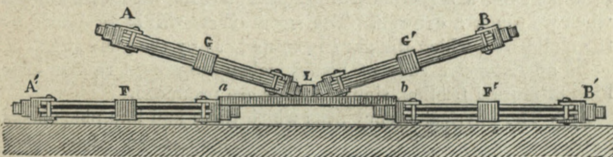

Fig. 249.

shows this phenomenon (*fig.* 247.). The angle which the needle makes with the horizontal plane is called the *dip*.

Artificial magnets are made by drawing the poles of other magnets, natural or artificial, along the surfaces of the bars to be magnetised.

Thus if the contrary poles *a*, *b* (*fig.* 248.) of two magnets be applied at the centre of a bar B′, A′ to be magnetised, and be drawn repeatedly towards its extremities, the bar will become an artificial magnet.

The process will be rendered more effectual if B′, A′ be laid upon the contrary poles A, B of two other magnets.

Another arrangement for performing this process with compound magnets is shown in *fig.* 249.

CHAP. XV.

ELECTRICITY.

484. If a glass tube, being well dried, be briskly rubbed with a dry woollen cloth, the following effects may be produced: —

The tube, being presented to certain light substances, such as feathers, metallic leaf, bits of light paper, filings of cork, or pith of elder, will attract them. If the friction take place in the dark, a bluish light will be seen to follow the motions of the cloth. If the glass be presented to a metallic body, or to the knuckle of the finger, a luminous spark, accompanied by a sharp cracking sound, will pass between the glass and the finger. On bringing the glass near the skin, a sensation will be produced like that which is felt when we touch a cobweb. The same effects will be produced by the cloth, with which the glass is rubbed, as by the glass itself.

In an extensive class of bodies, when submitted to the same kind of mutual friction, similar effects are produced.

485. The physical agency from which these and like phenomena arise has been called *electricity*, from the Greek word ἤλεκτρον (electron), signifying amber, that substance having been the first in which the property was observed by the ancients.

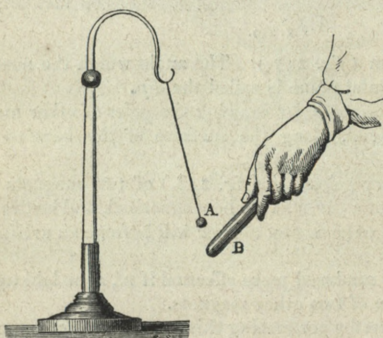

Fig. 250.

To study the laws which govern electrical forces, let an apparatus be provided, called an electric pendulum, consisting of a small ball A, *fig.* 250., about the tenth of an inch in diameter, turned from the pith of elder, and suspended, as represented in the figure, by a fine silken thread attached to a convenient stand.

If the glass tube B, after being rubbed as above described, be brought into contact successively with two pith balls thus suspended, and then separated from them, a property will be imparted to the balls, in virtue of which they will be repelled by the glass tube when it is brought nearer them, and they will in like manner repel each other when brought into proximity.

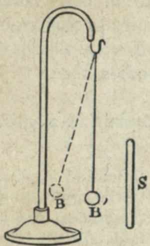

Fig. 251.

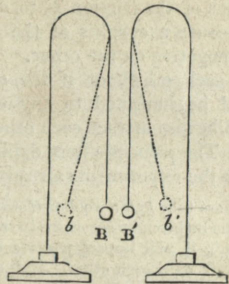

Fig. 252.

Thus, if the glass tube S (*fig.* 251.) be brought nearer the ball B′, the ball will depart from its vertical position, and will incline itself from the tube in the position B.

If the two balls, being previously brought into contact with the tube, be placed near each other, as in *fig.* 252., they will incline from each other, departing from the vertical positions B and B′, and taking the positions *b* and *b′*.

486. These, and a great variety of other phenomena which will be presently noticed, are usually explained by the supposition that all bodies in their natural state are pervaded by a compound fluid called *electricity*, consisting of two constituents, the one called the *positive*, and the other the *negative fluid.* Each of these component fluids is self-repulsive; that is to say, two bodies, both pervaded by the positive fluid, would repulse each other, and the same would be true of two bodies pervaded by the negative fluid. But if two bodies be pervaded, one by the positive and the other by the negative fluid, they will attract each other by virtue of the mutual attraction of the fluids with which they are charged.

487. If a body have a surplus of the positive fluid, it will repel another body which also has a surplus of positive fluid, and the same will be true of two bodies each of which has a surplus of negative fluid; but if one body have a surplus of the positive and the other a surplus of the negative fluid, they will attract each other.

488. This is a brief statement of the theory which is commonly known by the *hypothesis of two fluids*, and it is that which is now generally adopted by physical writers.

489. There is, however, another hypothesis adopted by Franklin, which consists in the supposition of a single fluid, but as this is now for the most part rejected, we shall not here enlarge upon it.

490. When two bodies submitted to mutual friction are thereby electrified, the phenomenon is explained by the supposition that the effect of the friction is to decompose their natural electricity, and to cause a surplus of the positive fluid to collect upon one, and of negative on the other. The two bodies in this case would attract each other, or if the surplus fluids with which they are charged be imparted to any other two bodies, these two bodies would likewise attract each other.

491. The principle here explained will explain in a satisfactory manner the experiments already stated.

If a glass tube and a woollen cloth be submitted to mutual friction, and the glass tube be brought successively into contact with the two balls B and B′ (*fig.* 252.), it will impart positive electricity to these balls, and they will accordingly repel each other. If the woollen cloth be brought into contact with them, the like effect will ensue, because they will be both charged with negative electricity; but if one be touched with the glass tube, and the other with the woollen cloth, one will be charged with positive and the other with negative electricity, and they will attract each other.

492. Positive electricity is sometimes called *vitreous*, and negative electricity *resinous;* but we shall here adhere to the more generally received terms positive and negative.

Bodies differ from each other in a striking manner in the freedom with which the electric fluid moves upon them. If that fluid be imparted to the surface of glass or wax, it will be confined strictly to that portion of the surface which originally receives it; but if it be imparted to a portion of the surface of a metallic body, it will instantaneously diffuse itself uniformly over the entire extent of such metallic surface, exactly as water would spread itself uniformly over a level surface on which it is poured.

The former class of bodies, which do not give free motion to the electric fluid on their surface, are called *nonconductors;* and the latter, on which unlimited freedom of motion prevails, are called *conductors*.

493. Of all bodies the most perfect conductors are the metals. These bodies transmit electricity instantaneously, and without any sensible obstruction, provided their dimensions are not too small in relation to the quantity of electricity imparted to them.

494. Good nonconductors are also called *insulators*, because when any body suspended by a nonconducting thread, or supported on a nonconducting pillar, is charged with electricity, such charge will be retained, since it cannot escape by the thread or pillar, which refuses a passage to it in virtue of its nonconducting quality. Thus, a globe of metal supported on a glass pillar, or suspended by a silken cord, being charged with electricity will retain the charge; whereas, if it were supported on a metallic

pillar, or suspended by a metallic wire, the electricity would pass away by its free motion over the surface of the pillar or the wire.

495. *Insulating stools* are formed with glass legs, so that any body charged with electricity and placed upon them will retain its electric charge.

If two persons stand on two insulating stools, and one strike the other two or three times with the fur of a cat, he that strikes will have his body positively, and he that is struck negatively, electrified, as may be ascertained by the method already explained, of presenting to them successively the pith ball B, *fig.* 251., previously charged with positive electricity. It will be repelled by the body of him that strikes, and attracted by that of him who is struck. But if the same experiment be made without placing the two persons on insulating stools, the same effects will not ensue; because, although the electricities are developed as before by the action of the fur, it immediately escapes through the feet to the ground.

496. *The atmosphere is a nonconductor*, for if it gave a free passage to electricity, the electrical effects excited on the surface of any body surrounded with it would soon pass away; and no electrical phenomena of a permanent nature could be produced, unless the bodies were removed from the contact of the air. It is found, however, that resin and glass, when excited by friction, retain their electricity for a considerable time.

497. *Rarefied air is a conductor*, for an electrified body soon loses its electricity if placed in the exhausted receiver of an air-pump. The electric fluid may, therefore, be considered as forming a coating upon the surface of electrified bodies, and as being held upon them by the tension or pressure of the surrounding air.

In the experiments described in *fig.* 250. *et seq.* with the pith balls, the silken string by which they are suspended acts as an insulator. The pith of elder being a conductor, the electric fluid is diffused over the ball; but the silk being a nonconductor, it cannot escape. If the ball were suspended by a metallic wire attached to a stand composed of any conducting matter, the electricity would escape, and the effects described would not ensue. But if the metallic wire were attached to a glass rod or other nonconductor, the same effects would be produced. In that case the electricity would be diffused over the wire as well as over the ball.

498. Water, whether in the liquid or vaporous form, is a conductor, though of an order greatly inferior to the metals. This fact is of great importance in electrical phenomena. The atmosphere contains suspended in it always more or less aqueous vapour, the presence of which impairs its nonconducting property. Hence, electrical experiments always succeed best in cold and dry weather. Hence it appears why the most perfect nonconductors

lose their virtue if their surface be moist, the electricity passing by the conducting power of the moisture.

499. This circumstance also shows why it is necessary to dry previously the bodies, on which it is desired to develop electricity by friction. It will be apparent from what has been explained, that it would be more correct to designate bodies as good and bad conductors in various degrees, than as conductors and nonconductors. There exists no body which, strictly speaking, is either an absolute conductor or absolute nonconductor.

500. If two insulated conductors, one of which is charged with electricity, and the other in its natural state, be brought into contact, the electric fluid diffused on the former will spread itself over the surface of both, and its intensity at any point will be less in proportion to the magnitude of the surface over which it is diffused.

501. If a conductor charged with electricity be put into connection with the earth by a chain or wire carried from the conductor to the ground, the electricity will diffuse itself over the entire earth in common with the conductor, but as the magnitude of the earth is infinitely greater than that of the conductor, the result will be that the conductor will retain no sensible portion of electricity, and it will in effect be reduced to its natural state.

502. On this account the earth is said to be the *common reservoir* to which all electricity has a tendency to escape, and to which in fact it does escape, unless its passage be intercepted by nonconductors or insulators.

503. If several different conductors be simultaneously placed in contact with an insulated electrified conductor so as to form a communication between it and the ground, the electricity will always escape by the best conductor. Thus, if a metallic chain or wire be held in the hand, one end touching the ground, and the other being brought into contact with the conductor, no part of the electricity will pass into the hand, the chain being a better conductor than the flesh of the hand. But if, while one end of the chain touch the conductor, the other be separated from the ground, then the electricity will pass into the hand, and will be rendered sensible by a convulsive shock. If a body A, charged with electricity of either kind, be brought into proximity with another body B in its natural state, the fluid, with which A is surcharged, will act by attraction and repulsion on the two constituents of the natural electricity of B; attracting that of the contrary, and repelling that of the same kind. This effect is precisely similar to that produced on the natural magnetic fluid in a piece of iron, when the pole of a magnet is presented to it, as will be explained hereafter

504. If the body B in this case be a nonconductor, the electric fluid having no free mobility upon its surface, its decomposition will be resisted, and the body B will continue in its natural state, notwithstanding the attraction and repulsion exercised by A on the constituents of its natural electricity. But if B be a conductor, the fluids having freedom of motion on its surface, the fluid similar to that with which B is charged will be repelled to the side most distant from B, and the contrary fluid will be attracted to the side next to B. Between these regions a neutral line will separate those parts of the body B, over which the two opposite fluids are respectively diffused.

505. *Induction* is the action of an electrified body exerted at a distance upon the electricity of another body, and is evidently analogous to that which produces similar phenomena in the magnetic bodies.

506. The effect of induction upon a series of conductors in their natural state is illustrated in *fig.* 253., where C is a conductor, supposed to be charged with positive electricity. This electricity acts by induction upon the natural electricity of the conductor A B, attracting the negative and repelling the positive fluid, so that the negative fluid collects at the end A, nearest to C; and the positive is repelled to the end B, most remote from C. The positive

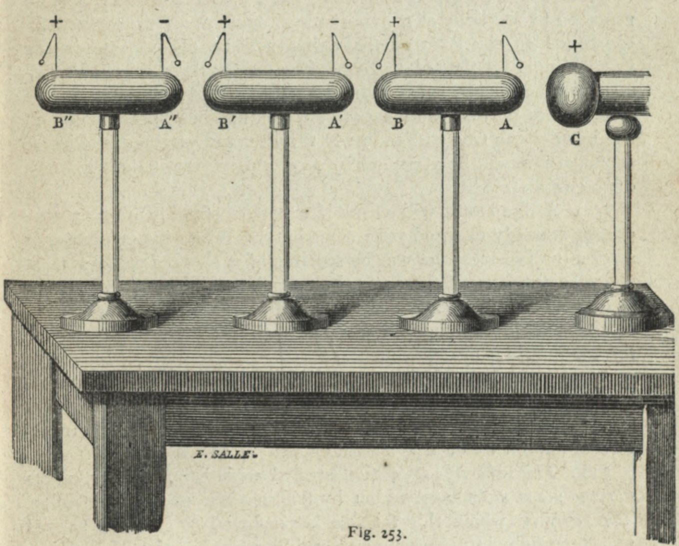

Fig. 253.

fluid thus repelled to B, acts in the same manner upon the natural electricity of the insulated conductor A′ B′, collecting the negative fluid at the end A′, and repelling the positive fluid to end B′. This positive fluid, thus collected at B′, reacts in like manner upon the natural electricities A″ B″, and so on.

In all cases whatever, the conductor, whose electrical state has been changed by the proximity of an electrified body, returns to its primitive electrical condition when the disturbing action of such body is removed; and this return is either instantaneous or gradual, according as the removal of the disturbing body is instantaneous or gradual.

507. It appears, therefore, that sudden and violent changes in the electrical condition of a conducting body may take place, without either imparting to or abstracting from such body any portion of electricity. The electricity with which it is invested before the inductive action commences, and after such action ceases, is exactly the same; nevertheless, the decomposition and recomposition of the constituent fluids, and their motion more or less sudden over it and through its dimensions, are productive often of mechanical effects of a very remarkable kind. This is especially the case with imperfect conductors, which offer more or less resistance to the reunion of the fluids.

508. If one of the conductors (*fig.* 253.) A B, for example, be replaced by the body of a living animal, such as a frog, the natural electricity of the body of the animal will be decomposed in the same manner as that of the conductor. If, under these circumstances, the electrified conductor C be suddenly removed, the electricities positive and negative which had been decomposed in the body of the frog will suddenly reunite, and produce an electric shock, which will be attended by a convulsive motion of the limbs of the animal.

509. A like result will ensue if a person stand close to a conductor strongly charged with electricity. When the conductor is suddenly discharged he will be sensible of a shock resulting from the recomposition of the natural electricity of his body.

510. *An electrical machine* is an apparatus, by means of which electricity is developed and accumulated, in a convenient manner for the purposes of experiment.

All electrical machines consist of three principal parts, the rubber, the body on whose surface the electric fluid is evolved, and one or more insulated conductors, to which this electricity is transferred, and on which it is accumulated.

511. *The rubber* is a cushion stuffed with hair, bearing on its surface some substance, which by friction will evolve electricity. The body on which this friction is produced is glass, so shaped and mounted as to be easily and rapidly moved against the rubber

with a continuous motion. This object is attained by giving the glass the form either of a cylinder revolving on its geometrical axis, or of a circular plate revolving in its own plane on its centre.

512. *The conductors* are bodies having a metallic surface and a great variety of shapes, and always mounted on insulating pillars, or suspended by insulating cords.

513. *The common cylindrical machine.* — A hollow cylinder of glass A B, *fig.* 254., is supported in bearings at C, and made to revolve by means of the wheels C and D connected by a band, a handle R being attached to the greater wheel.

The cushion H, represented separately in *fig.* 255., is mounted on a glass pillar, and pressed with a regulated force against the cylinder by means of springs fixed behind it. A chain K, *fig.* 254., connects the cushion with the ground. A flap of black silk equal in width to the cushion covers it, and is carried over the cylinder, terminating above the middle of the cylinder on the opposite side.

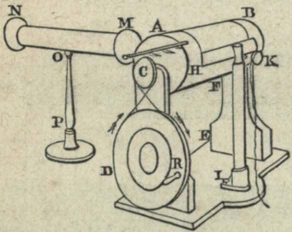

Fig. 254.

Fig. 255.

The conductor is a cylinder of thin brass M N, the ends of which are parts of spheres greater than hemispheres. It is supported by a glass pillar O P. To the end of the conductor next the cylinder is attached a row of points represented separately in *fig.* 256., which are presented close to the surface of the cylinder, but without touching it. The extent of this row of points corresponds with that of the rubber.

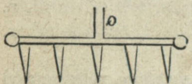

Fig. 256.

As the efficient performance of the machine depends in a great degree on the good insulation of the several parts, and as glass is peculiarly liable to collect moisture on its surface, which would impair its insulating virtue, it is usual to cover the insulating pillars of the rubber and conductor, and all that part of the cylinder which lies outside the cushion and silk flap, with a coating of resinous varnish, which, while its insulating property is more perfect than that of glass, offers less attraction to moisture.

To explain the operation of the machine, let us suppose that the cylinder is made to revolve by the handle R. Positive electricity is developed upon the cylinder, and negative electricity on the cushion. The latter passes by the conducting chain to the ground. The former is carried round under the flap, on the surface of the glass, until it arrives at the points projecting from the conductor There it acts by induction on the natural electricity of the conductor, attracting the negative electricity to the points and repelling the positive fluid. The negative electricity issuing from the points combines with and neutralises the positive fluid diffused on the cylinder, the surface of which, after it passes the points, is therefore restored to its natural state, so that when it arrives again at the cushion it is prepared to receive by friction a fresh charge of the positive fluid.

It is apparent, therefore, that the effect produced by the operation of this machine is a continuous decomposition of the natural electricity of the conductors, and an abstraction from it of just so much negative fluid as compensates for that which escapes by the cushion and chain to the earth. The conductor is thus as it were drained of its negative electricity by a stream of that fluid, which flowing constantly from the points passes to the cylinder, and hence by the cushion and chain to the earth. The conductor is therefore left surcharged with positive electricity.

514. Electrical machines have been constructed in a great variety of forms. That known as *Nairne's* is shown in *fig*. 257.

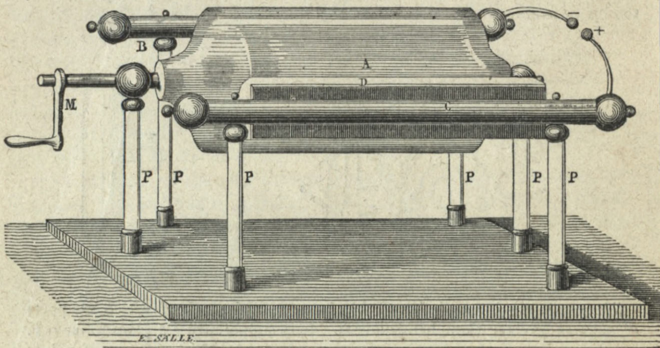

Fig. 257.

In this case there are two prime conductors, one of which, B, receives positive electricity from the glass cylinder, and the other, C, negative electricity from the cushion.

515. Another form, called the *common plate machine*, represented in *figs*. 258, 259., consists of a circular plate of glass rubbed against cushions by being made to revolve in contact with them. The decomposition of the electric fluid takes place in the same manner as above described, and the positive fluid is taken from the glass and carried off by one conductor, while the negative fluid passes to the earth by a chain.

In the arrangement shown in *fig*. 258., the rod X X′ being in contact with the cushions receives negative electricity, which is collected upon the ball G, and the rod Y Y′ positive electricity, which passes to the ground by a chain. In the arrangement shown in *fig*. 259., on the contrary, positive electricity is received by the ball G′ from the glass, while the negative electricity proceeds to the ground by the chain.

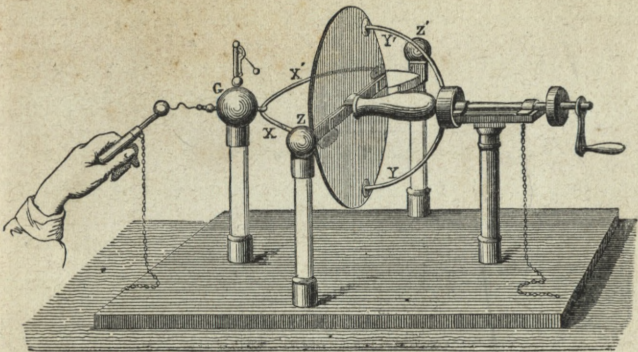

Fig. 258.

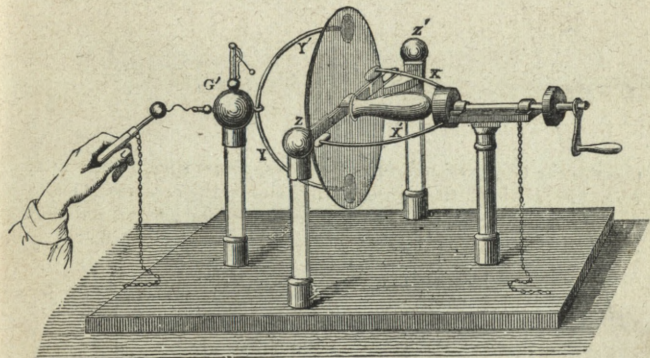

Fig. 259.

516. *Ramsden's plate machine.*—One of the earliest electric apparatus of this form is represented in *fig.* 260.

The large glass plate G, is mounted between wooden supports M *m*, and turned by a handle X. It is pressed between two pairs of rubbers, C C. In the direction of its horizontal diameter it passes between two curved brass tubes D D′, which collect the electricity from it by points in the usual way. These are connected with two large conductors B B′, supported on insulating pillars P P, and connected at the remote end by a cylindrical tube, from the middle of which another tube E proceeds at right angles, terminated in a knob.

After what has been explained of the other machines the theory of this will be readily understood

517. *Discharging rods.*—Since it is frequently necessary to

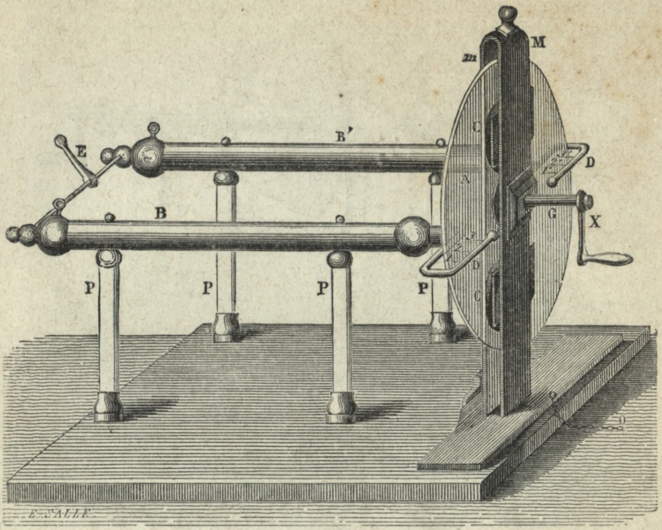

Fig. 260

observe the effects of points and spheres, pieces such as *figs.* 261, 262., are provided, to be inserted in holes in the conductors; also metallic balls, *figs.* 263, 264., attached to glass handles for cases in which it is desired to apply a conductor to an electrified body

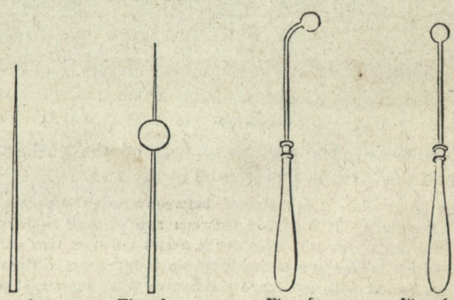

Fig. 261. Fig. 262. Fig. 263. Fig. 264.

without allowing the electricity to pass to the hand of the operator. With these rods the electricity may be taken from a conductor gradually by small portions, the ball taking by each contact only such a fraction of the whole charge as corresponds to the ratio of the surface of the ball to the surface of the conductor.

518. To establish a temporary connection between two conductors, or between a conductor and the ground, the jointed dischargers, *figs.* 265, 266., are useful. The distance between the

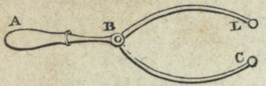

Fig. 265.

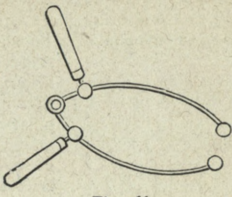
Fig. 266.

balls can be regulated at pleasure by means of the joint or hinge by which the rods are united.

519. The universal discharger, an instrument of considerable convenience and utility in experimental researches, is represented in *fig.* 267.

It consists of a wooden table to which two glass pillars A and A′ are attached. At the summit of these pillars are fixed two brass joints capable of revolving in a horizontal plane. To these joints are attached brass rods C C′, terminated by balls D D′, and having glass handles E E′. These rods play on joints at B B′, by which they can be moved in vertical planes.

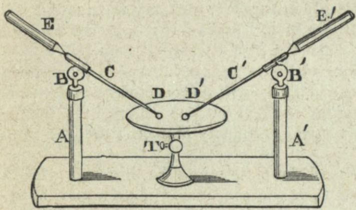

Fig. 267.

The balls D D′ are applied to a wooden table sustained on a pillar capable of having its height adjusted by a screw T. On the table is inlaid a long narrow strip of ivory, extending in the direction of the balls D D′. These balls D D′ can be unscrewed, and one or both may be replaced by forceps, by which may be held any substance through which it is desired to transmit the electric charge. One of the brass rods C is connected by chain or a wire with the source of electricity, and the other with the ground.

The electricity is transmitted by bringing the balls D D′ with the substance to be operated on between them, within such a distance of each other as will cause the charge to pass from one to the other through the introduced substance.

520. The *condenser* is in electricity what the microscope is in optics. It enables the observer to detect charges of electricity too minute to be sensible to any ordinary tests, by accumulating the electricity in greater quantities, just as the microscope magnifies the apparent diameter of a visible object.

The condenser consists of two circular plates of metal of equal size placed face to face with a thin coating of some non-conducting substance between them. One, called the *condensing plate*, is connected with the earth, and the other, called the *collecting plate*, is supported on an insulating pillar, and provided with means by which it can be placed in metallic connection with the body whose electrical state is under examination. Let us for brevity call the condensing plate A, and the collecting plate B, and let us suppose them to be mounted as shown in *fig.* 268., B being supported on a glass pillar, and provided with a metallic hook D, by which it can be put in communication with the body whose electricity is under examination; and A supported on a pillar provided with a hinge, by which it can be brought near to or removed from B at pleasure. Let us suppose also that the surface of one of these plates is coated with a thin varnish of resin or other insulating substance.

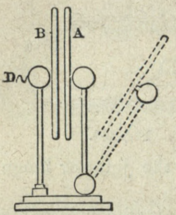

Fig. 268.

Let B be now put in metallic communication with a body feebly charged with positive electricity, for example. This electricity will be shared by the collecting plate B, and when the condensing plate A is brought into contact with the resinous coating of B, the electricity of B will act by induction on the natural electricity of A, and will decompose it, attracting the negative fluid and repelling the positive fluid to the earth. The negative fluid thus collected upon A will react by induction, not only on the positive fluid diffused over B and the body with which it is connected, accumulating it in a greater quantity upon B, but will also decompose the natural electricity of B, repelling the negative fluid towards the body with which B is connected, and attracting the positive fluid. In this way by reciprocal inductive action maintained between the plates A and B, a vast quantity of positive electricity will be collected upon the plate B, proceeding partly from its original charge, but much more from the decomposition by induction of the natural electricity of B, and the body with which it is connected.

When this effect has been produced the plate B may be disconnected with the body under examination, and then the condensing plate A may be removed, in which case the plate B will be strongly charged with positive electricity.

A strong charge can thus be produced upon the plate B, by means of the most feeble charge of the same electricity upon the body with which B is put in contact.

521. So long as the plate A is maintained in contact with B, the electricity with which it is charged by the inductive action of B will be in a peculiar state, which will prevent its escape from A to any other conductor with which A may be put in metallic connection. The electricity in this state is therefore said to be *dissimulated or latent*, and it is rendered free only when A is removed from B.

522. *The electrophorus* is an expedient by which a small charge of free electricity may be made to produce a charge of indefinite amount, which may be imparted to any insulated conductor.

This instrument consists of a circular cake, composed of a mixture of shell-lac, resin, and Venice turpentine, cast in a tin mould A (*fig.* 269.). Upon this is laid a circular metallic disc B, rather less in diameter than A, having a glass handle.

Before applying the disc B, the resinous surface is electrified negatively by striking it several times with the fur of a cat. The disc B being then applied to the cake A, and the finger being at the same time pressed upon the disc B (*fig.* 269.), to establish a communication with the ground through the body of the operator, a decomposition takes place by the inductive action of the negative fluid on the resin. The negative fluid escapes from the disc B through the body of the operator, and a positive charge remains, which is prevented from passing to the resin partly by the thin film of air which will

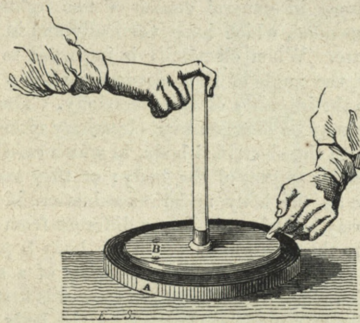

Fig. 269.

always remain between them, and partly by the non-conducting virtue of the resin.

When the disc B is thus charged with positive electricity kept latent on it by the influence of the negative fluid on A, the finger being previously re-

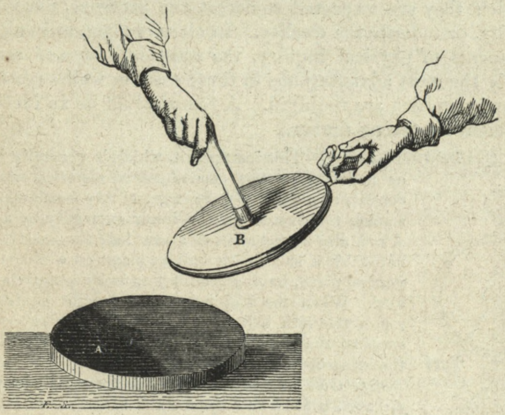

Fig. 270.

moved from the disc B, let it be raised from the resin, and the electricity upon it, before dissimulated, will become free, and may be imparted to any insulated conductor adapted to receive it. (*Fig.* 270.)

The charge of negative electricity remaining undiminished on the resin A, the operation may be indefinitely repeated; so that an insulated conductor may be charged to any extent, by giving to it the electric fluid drop by drop thus evolved on the disc B by the inductive action of A.

This is the origin of the name of the apparatus.

523. *Electroscopes* in general consist of two light conducting bodies freely suspended, which hang vertically and in contact, in their natural state. When electricity is imparted to them they repel each other, the angle of their divergence being greater or less according to the intensity of the electricity. These electroscopic substances may be charged with electricity either by direct communication with the electrified body, in which case their electricity will be similar to that of the body; or they may be acted upon inductively by the body under examination, in which case their electricity may be either similar or different from that of the body, according to the position in which the body is presented to them. In some cases the electroscope consists of a single light conductor, to which electricity of a known species is first imparted, and which will be attracted or repelled by the body under examination when presented to it, according as the electricities are unlike or like.

These instruments vary infinitely in form, arrangement, mode of application, and sensitiveness, according to the circumstances under which they are placed, and the intensities of the electricities of which they are expected to detect the presence, measure the intensity, or indicate the quality. In electroscopes, as in all other instruments of physical inquiry, the most delicate and sensitive are only the most advantageous in those cases in which much delicacy and precision are required. A razor would be an ineffectual instrument for felling timber.

524. *Quadrant electrometer.*— This instrument, which is generally used as an indicator on the conductors of electrical machines, consists of a pillar A B, *fig.* 271., of any conducting substance, terminated at the lower extremity by a ball B. A rod, also a conductor, of about half the length, terminated by a small pith ball D, plays on a centre C in a vertical plane, having behind it an ivory semicircle graduated. When the ball B is charged with electricity, it repels the pith ball D, and the angle of repulsion measured on the graduated arc supplies a rough estimate of the intensity of the electricity.

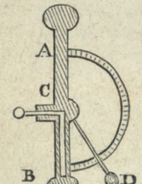

Fig. 271.

525. *Gold leaf electroscope.*— A glass cylinder A B C D, *fig.* 272., is fixed on a brass stand E, and closed at the top by a circular plate A B. The brass top G is connected by a metallic rod with two slips of gold leaf, of two or three

inches in length, and half an inch in breadth. In their natural state they hang in contact, but when electricity is imparted to the plate G, the leaves

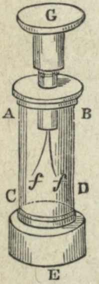

Fig. 272.

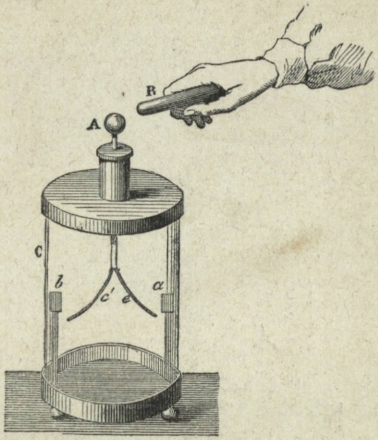

Fig. 273.

becoming charged with it indicate its presence, and in some degree its intensity, by their divergence. On the sides of the glass cylinder opposite the gold leaves are attached strips of tinfoil, communicating with the ground. When the leaves diverge so much as to touch the sides of the cylinder, they give up their electricity to the tinfoil, and are discharged. This instrument may also be affected inductively. If an electrified body B, *fig.* 273., be brought near to the knob A, its natural electricity will be decomposed; the fluid of the same name as that with which the body is charged will be repelled, will accumulate in the gold leaves *e e'*, and will cause them to diverge.

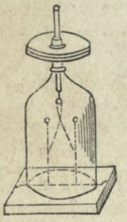

Fig. 274

526. *The condensing electroscope* is an instrument which has the same analogy to the common electroscope, as the compound has to the simple microscope. An electroscope with such an appendage is represented in *fig.* 274. The condenser is screwed on the top, the condensing plate communicating with the electroscope, and the collecting plate being laid over it. When the collecting plate is put into communication with the source of electricity to be examined, a charge is produced by induction in the condensing plate under it, and a charge of a contrary name is collected in the electroscope, the leaves of which will diverge, in this case, with an electricity similar in name to that of the body under examination.

The instrument and the manner of experimenting with it is represented on a larger scale in *figs.* 275. and 276.

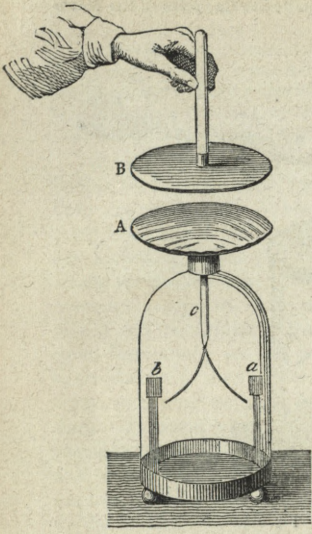

Fig. 275.

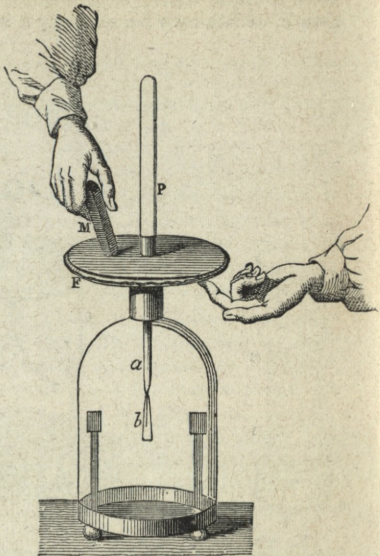

Fig. 276.

527. *The Leyden jar* is an instrument of great use in electrical investigations, the principle of which is in all respects similar to that of the condenser. It is usually constructed in the form of a cylinder A B, *fig*. 277., with a wide mouth and a flat bottom. The internal and external surfaces of the jar up to a certain height, C, are each coated with tinfoil, and the glass above C is improved in its insulating property by coating it with varnish of gumlac. A metallic rod terminated in a ball, D, descends into the jar, and is fixed in contact with the inner coating.

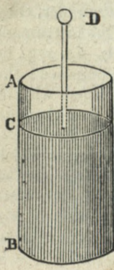

Fig. 277.

Now let us suppose that the outer coating is put into communication with the ground by means of a metallic chain, while the knob, D, is put in communication with the prime conductor of an electrical machine; the inner coating being charged with electricity from the prime conductor, and the outer coating communicating with the ground. The glass interposed between them exercises a mutual action, precisely similar to that of the collecting and condensing plates of the condenser already described. The outer coating of the air corresponds to the condensing plate, and its inner coating to the collecting plate; and it will be easily understood that by this means a charge of electricity of great strength is attracted from the prime conductor and retained by induction in the jar. This being the case, let us suppose that the connection between

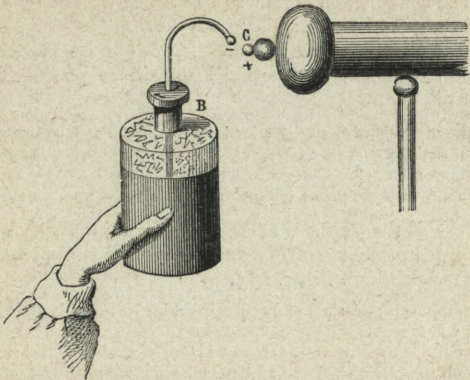

Fig. 278.

the knob D and the prime conductor is removed, and the knob D is put in metallic communication with the external coating of the jar. Immediately the positive electricity on the inside of the jar will be attracted by the nega-

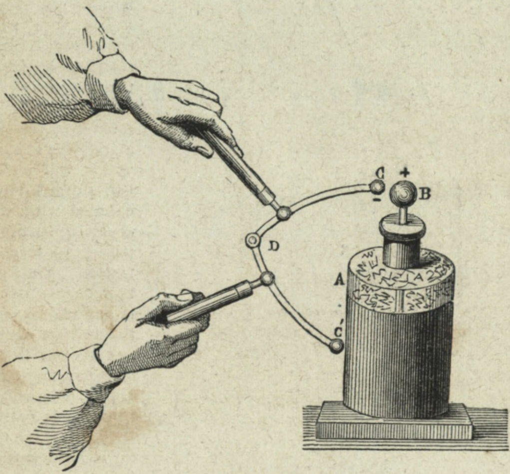

Fig. 279.

tive electricity outside, the two fluids will rush to each other, and electric equilibrium will be established.

528. The combination of the two contrary fluids may be made to pass through any intermediate body having sufficient conducting power to allow of their transit. If such an intervening body be that of an animal, an electric shock will be produced by the transit of the fluids.

One of the methods of charging a jar is shown in *fig.* 278., where the hand and body of the operator are the means by which the external coating is put into communication with the earth, while the internal coating is put into communication with the prime conductor C by means of a bent rod.

529. One of the methods of discharging a jar which has been charged in the manner described above by means of a jointed discharging rod, is shown in *fig.* 279.

530. An interesting method of discharging a jar is shown in *fig.* 280. The rod which enters the jar has attached to the top of it a small bell, I, placed near the bottle. On a convenient stand is a metallic rod supporting a similar bell E, level with I, and an electric pendulum consisting of a small copper ball suspended by a silken thread hangs between the two bells, so that it can be attracted and repelled by the one and the other. Supposing the jar to be charged, and its external coating connected with P by a conductor *e*, and the stand to be insulated, the free part of the positive electricity on the interior of the jar will attract the copper ball, which will strike the bell I; and becoming charged with positive electricity, will be repelled by I, and attracted by E; it will, therefore, strike against E, and will impart to it the positive electricity, and receive from it a charge of negative electricity, proceeding from the outside coating of the jar through the pillar P. The copper ball being negatively electrified, will then be repelled by E and attracted by I, against which it will

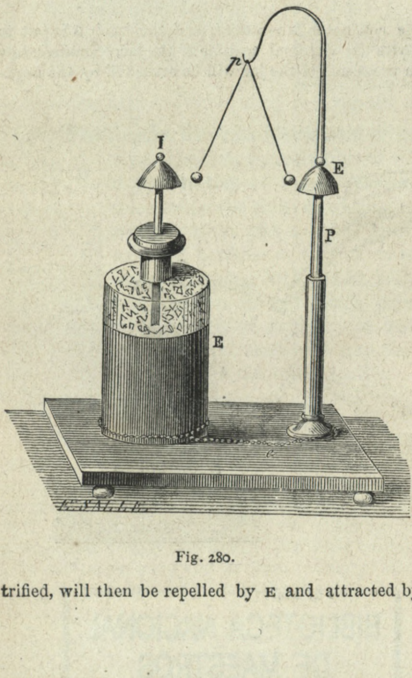

Fig. 280.

strike and will convey to the interior of the jar the negative fluid which it carries, receiving in exchange an equal charge of positive fluid. In this way the pendulum will continue to oscillate until the jar is discharged.

531. The metallic coatings of the jar have no other effect than to conduct the electricity to the surface of the glass, and when there to afford it a free passage from point to point.

532. To determine where the electricity resides, it is only necessary to provide means of separating the jar from the coating after it has been charged, and examining the electrical state of the one and the other.

For this purpose let a glass jar B, *fig.* 281., be provided, having a loose cylinder of metal C fitted to its interior, which can be placed in it or withdrawn from it at pleasure, and a similar loose cylinder A fitted to its exterior. The jar being placed in the external cylinder A, and the internal cylinder C being inserted in it, as shown at D, let it be charged with electricity by the machine in the manner already described. Let the internal cylinder be then removed, and let the jar be raised out of the external cylinder. The two coatings, being then tested by an electroscopic apparatus, will be found to be in their natural state. But if an electroscope be brought within the

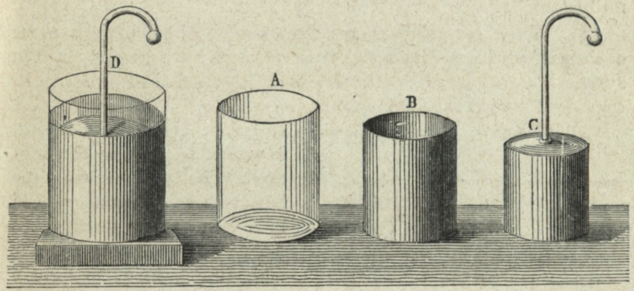

Fig. 281.

influence of the internal or external surface of the glass jar, it will betray the presence of the one or the other species of electricity. If the glass jar be then inserted in another metallic cylinder made to fit it externally, and a similar metallic cylinder made to fit it internally be inserted in it, it will be found to be charged as if no change had taken place. On connecting by metallic communication the interior with the exterior, the opposite electricities will rush towards each other and combine. It is evident, therefore, that the seat of the electricity, when a jar is charged, is not the metallic coating, but the surface of the glass under it.

533. In charging a single jar, an unlimited number of jars, connected together by conductors, may be charged with very nearly the same quantity of electricity.

For this purpose let the series of jars be placed on insulated stools, as represented in *fig.* 282., and let C be metallic chains connecting the external

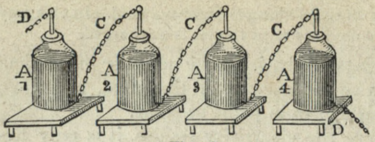

Fig. 282.

coating of each jar with the internal coating of the succeeding one. Let D be a chain connecting the first jar with the conductor of the machine, and D′ another chain connecting the last jar with the ground. The electricity conveyed to the inner coating of the first jar A acts by induction on the external coating of the first jar, attracting the negative electricity to the surface, and repelling the positive electricity through the chain C to the inner coating of the second jar. This charge of positive electricity in the second jar acts in like manner inductively on the external coating of this jar, attracting the negative electricity there, and repelling the positive electricity through the chain C to the internal coating of the third jar; and in the same manner the internal coating of every succeeding jar in the series will be charged with positive electricity, and its external coating with negative electricity. If, while the series is insulated, a discharger be made to connect the inner coating of the first with the outer coating of the last jar, the opposite electricities will rush towards each other, and the series of jars will be restored to their natural state.

534. When several jars are thus combined to obtain a more energetic discharge than could be formed by a single jar, the system is called an *electric battery*, and the method of charging it, explained above, is called *charging by cascade*.

535. *Common electric battery.* — It is not always convenient, however, to practise this method. The jars composing the battery are commonly placed in a box, as represented in *fig.* 283., coated on the inside with tinfoil, so as to form a metallic communication between the external coating of all the jars. The knobs, which communicate with their internal coating, are connected by a series of metallic rods in the manner represented in the figure; so that there is a continuous metallic communication between all the internal coatings. If the metallic rods which thus communicate with the inner coating be placed in communication with the conductor of a machine, while the box containing the jars is placed in metallic communication with the earth, the battery will be charged according to the principles already explained in the case of a single jar, and the force of its charge will be equal to the force of the charge of a single jar, the magnitude of whose external and internal coating would be equal to the sum of the internal and external coatings of all the jars composing the battery *fig.* 284.

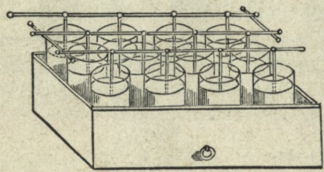
Fig. 283.

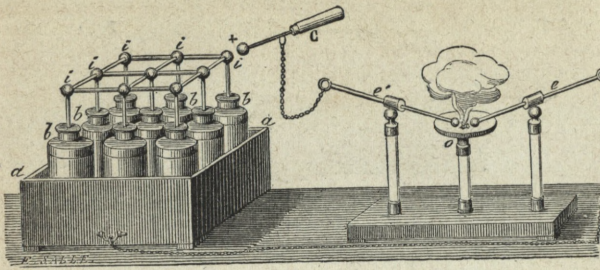

Fig. 284.

536. Points in general are found to favour the escape of electricity. Thus if a metallic point be inserted in a conductor charged with electricity, the electricity will pass from the conductor and escape in a sort of jet from the point. Various experiments are contrived with electric apparatus to illustrate this property of points.

In *figs.* 285, 286, apparatus are represented, by which a rotatory motion is produced by the reaction of the fluid issuing from the points, and by which a series of bells may be struck.

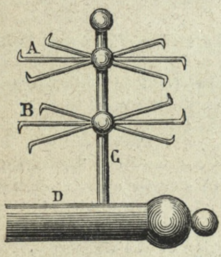

Fig. 285.

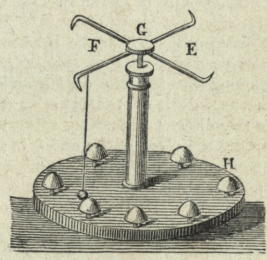

Fig. 286.

537. *The electrical blow pipe* consists of a metallic point projecting from the conductor of a machine, from which an electric current issues, the effect of which is to produce a current of air directed from the point so strong as to affect the flame of a candle, and even to blow it out.

This experiment may be made by placing the candle upon the conductor and presenting to its flame a metallic point, from which a stream of negative electricity will issue, so as to produce a similar current of air, *fig.* 287.

538. When the electric charge is transmitted through an imperfect conductor, remarkable mechanical effects are produced, the fluid in forcing its way through the conductor often piercing or bursting it.

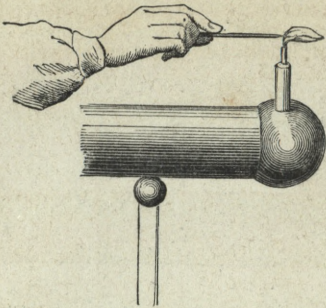

Fig. 287.

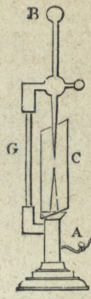

Fig. 288.

539. A method of exhibiting this effect is represented in *fig.* 288. The chain A communicates with the outside coating of the jar. The card C is placed in such a position that two metallic points touch it on opposite sides, terminating near each other. The pillar G, being glass, intercepts the electricity. The ball of the discharger, being put in communication with the inside coating of the jar, is brought into contact with the ball B, so that the two points which are on opposite sides of the card, being in connection with the two coatings of the jar, are charged with contrary fluids, which exert on each other such an attraction that they rush to each other, penetrating the card, which is found in this case pierced by a hole larger than that produced by a common pin.

It is remarkable that the *burr* produced on the surface of the card is in this case convex *on both sides*, as if the matter producing the hole, instead of passing through the card from one side to the other, had either issued from the middle of its thickness, emerging at each surface, or as if there were two distinct prevailing substances passing in contrary directions, each elevating the edges of the orifice in issuing from it.

The accordance of this effect with the hypothesis of two fluids is apparent.

540. A rod of wood half an inch thick may be split by a strong charge transmitted in the direction of its fibres, and other imperfect conductors pierced in the same manner.

If a leaf of writing paper be placed on the stage of the discharger, the electricity passed through it will tear it.

The charge of a jar will penetrate glass. An apparatus for exhibiting this effect is shown in *fig.* 289. It may also be exhibited by transmitting the charge through the side of a phial, *fig.* 290.

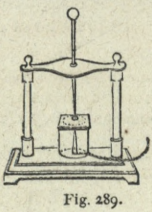

Fig. 289.

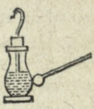

Fig. 290.

A strong charge passed through water, scatters the liquid in all directions around the points of discharge, *fig.* 291.

541. The alternate attraction and repulsion of electrified conductors is prettily illustrated by the *electrical bells.*

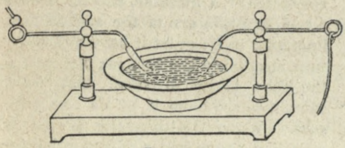

Fig. 291.

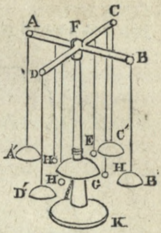

Fig. 292.

A B and C D, *fig.* 292., are two metal rods supported on a glass pillar. From the ends of these rods four bells A′ B′ C′ D′ are suspended by metallic chains. A central bell G is supported on the wooden stand which sustains the glass pillar E F, and this central bell communicates by a chain with the ground. From the transverse rods are also suspended, by silken threads, four small brass balls H. The transverse rods being put in communication with the conductor of an electrical machine, the four bells A′ B′ C′ D′ become charged with electricity. They attract and then repel the balls H, which when repelled strike the bell G, to which they give up the electricity they received by contact with the bells A′ B′ C′ D′, and this electricity passes to the ground by the chain. The bells will thus continue to be tolled as long as any electricity is supplied by the conductor to the bells A′ B′ C′ D′.

542. Let a metallic point be inserted into one of the holes of the prime conductor, so that, in accordance with what has been explained, a jet of electricity may escape from it when the conductor is electrified. Let this jet, while the machine is worked, be received on the interior of a glass tumbler, by which the surface of the glass will become charged with electricity.

If a number of pith balls be laid upon a metallic plate communicating with the ground, and the tumbler be placed with its mouth upon the plate, including the balls within it, the balls will begin immediately leaping violently from the metal and striking the glass, and this action will continue till all the electricity with which the glass was charged has been carried away.

This is explained on the same principle as the former experiments. The balls are attracted by the electricity of the glass, and when electrified by contact, are repelled. They give up their electricity to the metallic plate, from which it passes to the ground; and this process continues until no electricity remains on the glass of sufficient strength to attract the balls.

543. Let a disc of pasteboard or wood, coated with metallic foil, be suspended by wires or threads of linen from the prime conductor of an electrical machine, and let a similar disc be placed upon a stand capable of being adjusted to any required height. Let this latter disc be placed immediately under the former, and let it have a metallic communication with the ground. Upon it place small coloured representations in paper, of dancing figures, which are prepared for the purpose. When the machine is worked, the electricity with which the upper disc will be charged will attract the

light figures placed on the lower disc, which will leap upwards; and after touching the upper disc and being electrified, will be repelled to the lower disc, and this jumping action of the figures will continue so long as the machine is worked. An electrical dance is thus exhibited for the amusement of young persons.

544. Let a small metallic bucket B, *fig.* 293., be suspended from the prime conductor of a machine, and let it have a capillary tube C D of the syphon form immersed in it; or let it have a capillary tube inserted in the bottom; the bore of the tube being so small that water cannot escape from it by its own pressure. When the machine is put in operation, the particles of water, becoming electrified, will repel each other, and immediately an abundant stream will issue from the tube; and as the particles of water after leaving the tube still exercise a reciprocal repulsion, the stream will diverge in the form of a brush.

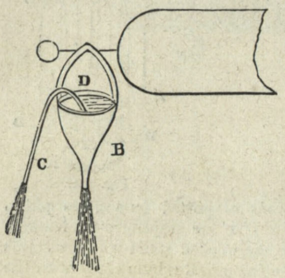

Fig. 293.

If a sponge saturated with water be suspended from the prime conductor of the machine, the water, when the machine is first worked, will drop slowly from it; but when the conductor becomes strongly electrified, it will descend abundantly, and in the dark will exhibit the appearance of a shower of luminous rain.

545. Let a piece of sealing-wax be attached to the pointed end of a metallic rod; set fire to the wax, and when it is in a state of fusion blow out the flame, and present the wax within a few inches of the prime conductor of the machine. Strongly electrified myriads of fine filaments will issue from the wax towards the conductor, to which they will adhere, forming a sort of network resembling wool. This effect is produced by the positive electricity of the conductor decomposing the natural electricity of the wax; and the latter being a conductor when in a state of fusion, the negative electricity is accumulated in the soft part of the wax near the conductor, while the positive electricity escapes along the metallic rod. The particles of wax thus negatively electrified, being attracted by the conductor, are drawn into the filaments above mentioned.

546. *a b*, *fig.* 294. is a small strip of wood covered over with silver leaf or tinfoil, insulated on *c* like a balance. A slight preponderance is given to it at *a*, so that it rests on a wire having a knob *m* at its top; *p* is a similar metal ball insulated. Connect *p* with the interior, and *m* with the exterior coating of the jar, charge it, and the see-saw motion of *a b* will commence from causes similar to those which excited the movements of the pith balls.

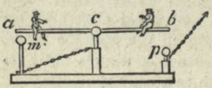

Fig. 294.

547. The transmission of electric discharges through imperfect conductors, or even through comparatively perfect ones, is attended with a certain development of heat.

If a piece of wire of several inches in length be placed upon the stage of the universal discharger, a feeble charge transmitted through it will sensibly raise its temperature. By increasing the strength of the charge, its temperature may be elevated to higher and higher points of the thermometric scale; it may be rendered incandescent, fused, vaporised, and, in fine, burned. Van Marum fused pieces of wire above 70 feet in length.

548. The worst conductors of electricity, such as platinum and iron, suffer much greater changes of temperature by the same charge than the best conductors, such as gold and copper. The charge of electricity, which only elevates the temperature of one conductor, will sometimes render another incandescent, and will volatilise a third.

If a fine silver wire be extended between the rods of the universal discharger, a strong charge will make it burn with a greenish flame. It will pass off in a greyish smoke. Other metals may be similarly ignited, each producing a flame of a peculiar colour. If the experiments be made in a receiver, the products of the combustion, being collected, will prove to be the metallic oxides. If a gilt thread of silk be extended between the rods of the discharger, the electricity will volatilise or burn the gilding, without affecting the silk. The effect is too rapid to allow the time necessary for the heat to affect the silk.

A strip of gold or silver leaf placed between the leaves of paper, being extended between the rods of the discharger, will be burnt by a discharge from a jar having two square feet of coating. The metallic oxide will in this case appear on the paper as a patch of purple colour in the case of gold, and of grey colour in that of silver.

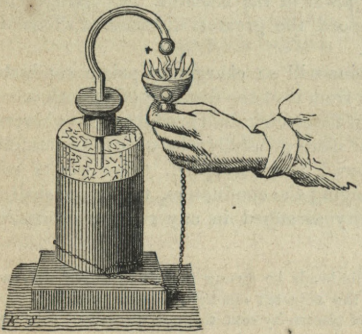

Fig 295.

549. Ether or alcohol may be fired by passing through it an electric discharge, *fig.* 295.

550. If the conductor of an ordinary electric machine while in operation be connected with the ground by a thick metallic wire, the current of the fluid which flows along the wire to the ground will not be sensibly luminous; but if the machine be one of great power, such, for example, as the Taylerian machine of Haarlem, an iron wire of 60 or 70 feet long, communicating with the ground and conducting the current, will be surrounded by a brilliant light. The intensity of the electricity necessary to produce this effect, depends altogether on the

properties of the medium in which the fluid moves. Sometimes electricity of feeble intensity produces a strong luminous effect, while in other cases electricity of the greatest intensity develops no sensible degree of light.

551. The luminous phenomenon called the electric spark does not consist, as the name would imply, of a luminous point which moves from the one body to the other. Strictly speaking, the light manifests no progressive motion. It consists of a *thread of light*, which for an instant seems to connect the two bodies, and in general is not extended between them in one straight unbroken direction like a thread which might be stretched tight between them, but has a zigzag form, resembling more or less the appearance of lightning, *fig*. 296.

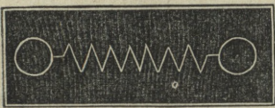

Fig. 296.

If the part of either of the bodies which is presented to the other have the form of a point, the electric fluid will escape, not in the form of a spark, but as an *aigrette*, or brush light, the diverging rays of which sometimes have the length of two or three inches.

552. If the knuckle of the finger or a metallic ball at the end of a rod held in the hand be presented to the prime conductor of a machine in operation, a spark will be produced, the length of which will vary with the power of the machine. By the *length of the spark* must be understood the greatest distance at which the spark can be transmitted.

A very powerful machine will so charge its prime conductor that sparks may be taken from it at the distance of 30 inches.

553. Since the passage of the electric fluid produces light wherever the metallic continuity, or more generally wherever the continuity of the conducting material is interrupted, these effects may be multiplied by so arranging the conductors, that there shall be interruptions of continuity arranged in any regular or desired manner.

554. If a number of metallic beads be strung upon a thread of silk, each bead being separated from the adjacent one by a knot on the silk so as to break the contact, a current of electricity sent through them will produce a series of sparks, a separate spark being produced between every two successive beads. By placing one end of such a string of beads in contact with the conductor of the machine, and the other end in metallic communication with the ground, a chain of sparks can be maintained so long as the machine is worked. The beads may be disposed so as to form a variety of fancy designs, which will appear in the dark in characters of light.

Similar effects may be produced by attaching bits of metallic foil to glass. Sparkling tubes and plates are contrived in this manner, by which amusing experiments are exhibited. A glass plate is represented in *fig*. 297., by

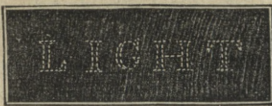

Fig. 297.

which a word is made to appear in letters of light in a dark room. The letters are formed by attaching lozenge-shaped bits of tinfoil to the glass, disposed in the proper form. In the same manner designs may be formed on the inner surface of glass tubes, or plates, or, in fine, of glass vessels of any form.

In these cases the luminous characters may be made to appear in lights of various colours, by using spangles of different metals, since the colour of the spark varies with the metal.

555. When the electric fluid passes through air, the brilliancy and colour of the light evolved depends on the density of the air. In rarefied air the light is more diffused and less intense, and acquires a reddish or violet colour. Its colour, however, is affected, as has been just stated, by the nature of the conductors between which the current flows. When it issues from gold the light is green, from silver red, from tin or zinc white, from water deep yellow inclining to orange.

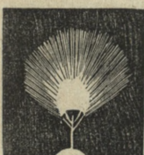
Fig. 298.

It is evident that these phenomena supply the means of constructing electrical apparatus by which an infinite variety of beautiful and striking luminous effects may be produced.

When the electricity escapes from a metallic point in the dark, it forms an aigrette, *fig.* 298., which will continue to be visible so long as the machine is worked.

The luminous effect of electricity in rarefied air is exhibited by an apparatus, *fig.* 299., consisting of a glass receiver, which can be screwed upon the plate of an air pump and partially exhausted. The electric current passes between two metallic balls attached to rods, which slide in air-tight collars in the covers of the receiver.

It is observed that the aigrettes formed by the negative fluid are never as long or as divergent as those formed by the positive fluid, an effect which is worthy of attention as indicating a distinctive character of the two fluids.

This phenomenon may be exhibited in a still more remarkable manner by using, instead of the receiver, a glass tube two or three inches in diameter, and about thirty inches in length. In this case a pointed wire being fixed to the interior of each of the caps, one is screwed upon the plate of the air pump, while the external knob of the other is connected by a metallic chain with the prime conductor of the electrical machine. When the machine is worked in the dark, a succession of luminous phenomena will be produced in the tube, which bear so close a resemblance to the aurora borealis as to suggest the most probable origin of that meteor. When the exhaustion of the tube is nearly perfect, the whole length of the tube will exhibit a violet red light. If a small quantity of air be admitted, luminous flashes will be seen to issue from the two points attached to the caps. As more and more air is admitted, the flashes of light which glide in a serpentine form down the interior of the tube will become more thin and white, until at last the electricity will cease to be diffused through the column of air, and will appear as a glimmering light at the two points.

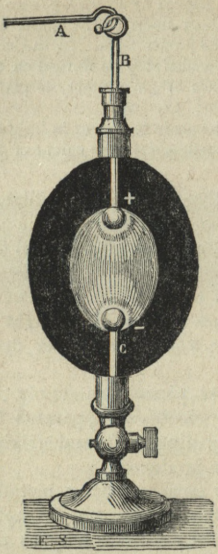

Fig. 299.

556. The material substances which enter into the composition of the bodies of animals are generally imperfect conductors. When such a body, therefore, is placed in proximity with a conductor charged with electricity, its natural electricity is decomposed, the fluid of a like name being repelled to the side more remote from, and the fluid of the contrary name being attracted to the side nearest to, the electrified body. If that body be very suddenly removed from or brought near to the animal body, the fluids of the latter will suddenly suffer a disturbance of their equilibrium, and will either rush towards each other to recombine, or be drawn from each other, being decomposed; and owing to the imperfection of the conducting power of the fluids and solids composing the body, the electricity in passing through it will produce a momentary derangement, as it does in passing through air, water, paper, or any other imperfect conductor. If this derangement do not exceed the power of the parts to recover their position and organisation, a convulsive sensation is felt, the violence of which is greater or less according to the force of electricity and the consequent derangement of the organs; but if it exceed this limit, a permanent injury, or even death, may ensue.

557. It will be apparent from this, that the nervous effect called the *electric shock* does not require that any electricity be actually imparted to, abstracted from, or passed through the body. The momentary derangement of the natural electricity is sufficient to produce the effect with any degree of violence. The shock produced thus by induction, without transmitting electricity through the body, is sometimes called the *secondary shock.*

The physiological effects of electricity are extremely various, according to the quantity and intensity of the charge, according to the part of the body affected by it, and according to the manner in which it is imparted.

558. A shock has in this manner been sent through a regiment of soldiers. At an early period in the progress of electrical discovery, M. Nollet transmitted a discharge through a series of 180 men; and at the convent of Carthusians a chain of men being formed extending to the length of 5400 feet, by means of metallic wires extended between every two persons composing it, the whole series of persons was affected by the shock at the same instant.

Experiments on the transmission of the shock were made in London by Dr. Watson, in the presence of the Council of the Royal Society, when a circuit was formed by a wire carried from one side of the Thames to the other over Westminster Bridge. One extremity of this wire communicated with the interior of a charged jar, the other was held by a person on the opposite bank of the river. This person held in his other hand an iron rod which he dipped in the river. On the other side near the jar stood another person, holding in one hand a wire communicating with the exterior coating of the jar, and in the other hand an iron rod. This rod he dipped into the river, when instantly the shock was received by both persons, the electric fluid having passed over the bridge, through the body of the person on the other side, through the water across the river, through the rod held by the other person, and through his body to the exterior coating of the jar. Familiar as such a fact may now appear, it is impossible to convey an adequate idea of the amazement bordering on incredulity with which it was at that time witnessed.

CHAP. XVI.

VOLTAIC ELECTRICITY.

559. Let C, *fig.* 300., be a piece of copper, Z, a piece of zinc, and L, an acidulated liquid placed between them, so as to be in contact with each. A decomposition of the natural electricity of the combination will immediately take place, the positive fluid passing towards the copper, and the negative towards the zinc.

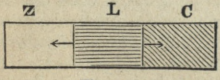

Fig. 300.

If a wire of any length be placed with one end attached to the copper, and the other to the zinc, the positive fluid will flow along the wire from the copper to the zinc, and the negative from the zinc to the copper, and this flowing of the two fluids will continue for an indefinite time.

560. Electricity thus evolved is called *voltaic electricity*, and the

current produced along the wire is called a *voltaic current.* Although there are, in fact, two contrary currents passing along the wire as just stated, one consisting of the positive, and the other of the negative fluid, it is customary only to consider the positive fluid, and the current is accordingly said to flow from the copper to the zinc along the wire, and from the zinc to the copper through the liquid. The copper extremity is called the *positive pole* of the combination, and the zinc extremity the *negative pole.*

561. The form given to the zinc and copper, and the manner in which the acidulated liquid is interposed between them are very various.

Thus a copper vessel C C (*fig.* 301.), being filled with acidulated liquid a cylinder of zinc may be immersed in it without touching it. The two materials will thus be placed with the acidulated liquid in contact with each. A wire, in this case C P, is connected with the copper vessel, and another Z N with the zinc. According to what has been stated, a decomposition of the natural electricities will ensue, the positive fluid being collected upon the wire C P, and the negative upon the wire Z N. If these two wires be connected with each other by means of any continuous wire carried from P to N, a voltaic current will pass along the connecting wire from P to N. P will then be the positive and N the negative pole of the combination.

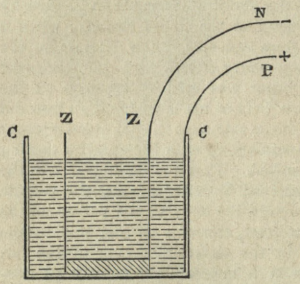

Fig. 301.

562. Sometimes two different acid or saline solutions are used as a more effective method of developing voltaic electricity. Such an arrangement may be made as follows.

The hollow cylinder of zinc Z Z, open at both ends as already described, is placed in a vessel of glazed porcelain V V (*fig.* 302.). Within this is placed a cylindrical vessel *v v*, of unglazed porcelain, a little less in diameter than the zinc Z Z, so that a space of about a quarter of an inch may separate their surfaces. In this vessel *v v* is inserted a cylinder C C of platinum, open at the ends, and a little less than *v v*, so that their surfaces may be about a quarter of an inch asunder. Dilute sulphuric acid is then poured into the vessel V V, and concentrated nitric acid into *v v*. P proceeding from the platinum will then be the positive, and N proceeding from the zinc the negative pole.

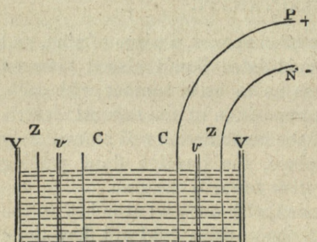

Fig. 302.

563. This arrangement is known as *Grove's battery.*

As usually constructed, it is represented in *figs.* 303. and 304., where G is a cylindrical jar of glass or porcelain nearly filled with water, acidulated with sulphuric acid. Z is a cylinder of zinc open at both ends, and having an

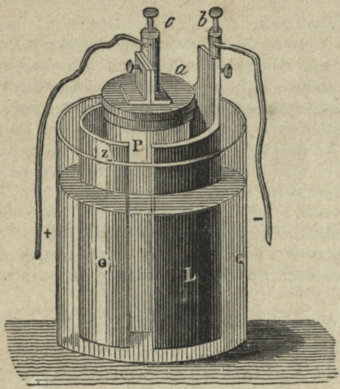

Fig. 303.

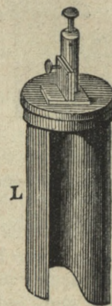

Fig. 304.

opening in the side passing from end to end. P is a vase of unglazed porcelain or earthenware, filled with nitric acid; and in fine L is a leaf of platinum bent to the form of S, as shown in *fig.* 304., and attached to a cover, *a*, *fig.* 303., which is placed upon the porous vase P. A metallic rod *c*, communicating with the leaf of platinum, is connected with a copper wire, which serves as the positive pole, while a second wire, fixed to the zinc at *b*, is the negative pole.

One of the objections to this arrangement is the costly character of the platinum, and the circumstance, that when it has been in use for a certain time that metal becomes so brittle that the least accidental disturbance will break it.

564. The voltaic system known as *Bunsen's* is similar to the preceding, substituting charcoal for platinum.

The electro-motive forces of Grove's and Bunsen's batteries are considered to be, *cæteris paribus*, equal.

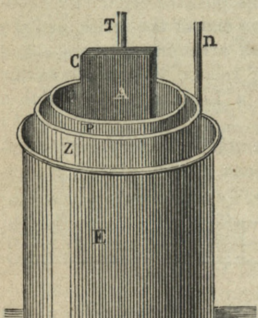

Fig. 305.

The apparatus, with all its parts combined, so as to develop the voltaic current, is shown in *fig.* 305., where the zinc cylinder Z is placed in the glazed vase E, the unglazed cylinder P within the zinc, and the charcoal cylinder C immersed in the nitric acid contained in P.

565. The voltaic arrangement known as Daniel's constant battery consists of a copper cylindrical vessel c c (*fig.* 306.), widening near the top *a d.*

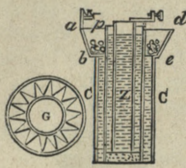

Fig. 306.

In this is placed a cylindrical vessel of unglazed porcelain *p.* In this latter is placed the hollow cylinder of zinc z, already described. The space between the copper and porcelain vessels is filled with a saturated solution of the sulphate of copper, which is maintained in a state of saturation by crystals of the salt placed in the wide cup *a b c d,* in the bottom of which is a grating composed of wire carried in a zigzag direction between two concentric rings, as represented in plan at G. The vessel *p,* containing the zinc, is filled with a solution of sulphuric acid containing from 10 to 25 per cent. of acid when great electro-motive power is required, and from 1 to 4 per cent. when more moderate action is sufficient.

566. Whatever may be the efficacy of a simple voltaic combination such as those described above, the electricity developed by them is incomparably more feeble than that which proceeds from other agencies, and, indeed, so feeble, that without some expedient by which its power can be augmented in a very high ratio, it would possess very little importance as a visible agent. It happens, however, that its efficacy may be augmented with scarcely any limit, by uniting together, in a continued series, a number of such combinations, in such a manner that the positive electricity developed by each should flow towards one end of the series, and the negative towards the other end. Such arrangements are called *voltaic piles,* or *voltaic batteries,* being related to a simple voltaic combination in the same manner as a Leyden battery is to a Leyden jar.

567. To explain the principle of the voltaic battery, let us suppose several simple voltaic combinations, $z^1 L^1 c^1$, $z^2 L^2 c^2$, $z^3 L^3 c^3$,

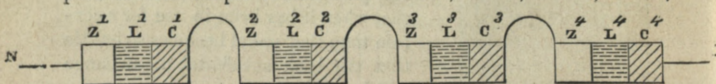

Fig. 307.

$z^4 L^4 c^4$, *fig.* 307., to be placed so that the negative poles z shall all look to the left and the positive c to the right. Let the metallic plates c be extended, and bent into an arc, so as to be placed in contact with the plates z. Let the entire series be supposed to stand upon any insulating support, and let the negative pole z^1 of the first combination of the series be put in connection with the ground by a conductor.

According to what has been explained, the positive electricity developed in the first combination, will collect upon c^1, and the negative upon z^1, but the positive electricity thus collected upon c^1 will flow along the wire to z^2, and will pass to c^2. Meanwhile, electricity will be in like manner decomposed in the second combination, the positive fluid collecting on c^2 and there uniting with the positive fluid which has already passed from the first combination. The negative fluid meanwhile collected upon z^2 passes along the wire to z^1. The positive fluid accumulated upon c^2 passes along the wire to the third combination, and accumulates on c^3, together with the positive fluid developed in the third combination, while the negative fluid developed in the third combination flows back over the wire through the second combination to the first, and accumulates on z^1. In this way it will be seen that all the positive fluid developed in the different series will flow to the last copper element c^4, and all the negative fluid to the first zinc element z^1.

If one extremity of wire be connected with c^4 and the other with z^1, a voltaic current will be established along the wire from c^4 to z^1, consisting of the accumulated fluid developed by the combination of the apparatus.

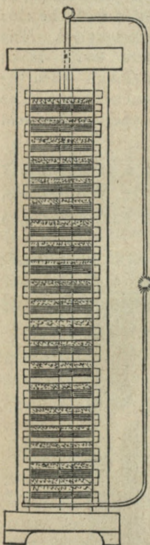

Fig. 308.

If it be assumed that each combination develops an equal quantity of the electric fluid, the intensity of the current will always be proportional to the number of combinations which enter the composition of the battery.

568. The first pile constructed by Volta was formed as follows: —

A disc of zinc was laid upon a plate of glass. Upon it was laid an equal disc of cloth or pasteboard soaked in acidulated water. Upon this was laid an equal disc of copper. Upon the copper were laid in the same order three discs of zinc, wet cloth, and copper, and the same superposition of the same combinations of zinc, cloth, and copper was continued until the pile was completed. The highest disc (of copper) was then the positive, and the lowest disc (of zinc) the negative pole, according to the principles already explained. It was usual to keep the discs in their places by confining them between rods of glass.

Such a pile, with conducting wires connected with its poles, is represented in *fig.* 308.

569. The next arrangement proposed by Volta formed a step towards the form which the pile definitely assumed, and is known under the name of the *couronne des tasses* (ring of cups): this is represented in *fig.* 309., and consists of a series of cups or glasses containing the acid solution.

Rods of zinc and copper Z C, soldered together end to end, are bent into the form of arcs, the ends being immersed in two adjacent cups, so that the metals may succeed each other in one uniform order. A plate of zinc, to which a conducting wire N is attached, is immersed in the first: and a similar plate of

Fig. 309.

copper, with a wire P, in the last cup. The latter wire will be the positive, and the former the negative, pole.

570. The next form of voltaic pile proposed was that of Cruikshank, represented in *fig*. 310.

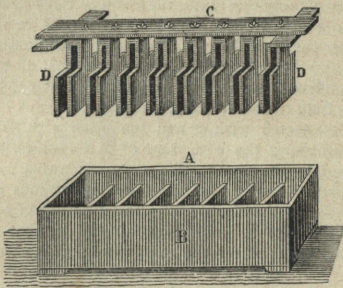

Fig. 310.

This consisted of a trough of glazed earthenware divided into parallel cells corresponding in number and magnitude to the pairs of zinc and copper plates which were attached to a bar of wood, and so connected that, when immersed in the cells, each copper plate should be in connection with the zinc plate of the next cell. The plates were easily raised from the trough when the battery was not in use. The trough contained the acid solution.

571. Voltaic batteries have been constructed in a great variety of forms, but the principle is nearly the same. Dr. Wollaston's, for example, consisted of a double plate of copper surrounding a plate of zinc without touching it, *fig*. 311

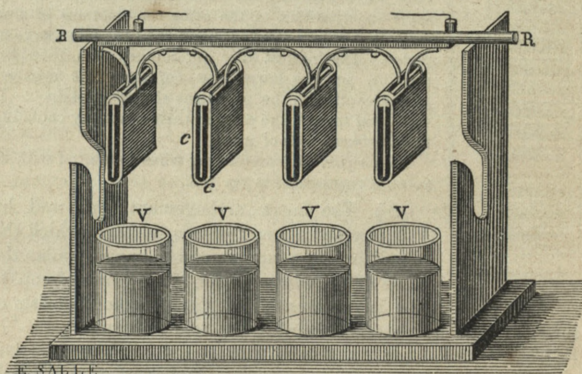

Fig. 311.

572. If the conducting wires connected with the poles P and N, instead of being connected together, be connected with the ground, the *earth itself* will take the place and play the part of the conducting wire in relation to the current. The positive fluid will

in that case flow by the wire P E, *fig.* 312., and the negative fluid by the wire N E′ to the earth; and the two fluids will be transmitted through the earth E E′ in contrary directions, exactly in the same manner as through the conductor. In this case, therefore, the voltaic circuit is completed by the *earth itself.*

573. In all cases, in completing the circuit, it is necessary to insure perfect contact wherever two different conductors are united. This contact may be insured by pressing the wires

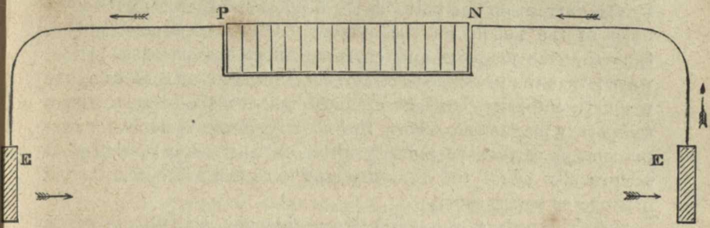

Fig. 312.

together in a metallic clamp, or inserting their extremities, carefully cleaned, in cups containing mercury. When the earth is used to complete the circuit, these are inapplicable. To insure the unobstructed flow of the current in this case, the wire is soldered to a large plate of metal, having a surface of several square feet, which is buried in the moist ground, or, still better, immersed in a well or other reservoir of water.

574. In cities, where there are extensive systems of metallic pipes buried for the convenience of water or gas, the wires proceeding from the poles P and N may be connected with these.

There is no practical limit to the distance over which a voltaic current may in this manner be carried, the circuit being still completed by the earth. Thus, if while the pile P N, *fig.* 312., is at London, the wire P E is carried to Paris or Vienna (being insulated throughout its entire course), and is put in communication with the ground at the latter place, the current will return to London through the earth E E′, as surely and as promptly as if the points E, E′ were only a foot asunder.

CHAP. XVII.

ELECTRO-MAGNETISM.

575. When a voltaic current is placed near a magnetic needle, certain motions are imparted to the needle or to the conductor of the current, or to both, which indicate the action of forces exerted by the current on the poles of the needle, and reciprocally by the poles of the needle on the current. Other experimental tests show that the magnets and currents affect each other in various ways; that the presence of a current increases or diminishes the magnetic intensity, imparts or effaces magnetic polarity, produces temporary magnetism where the coercive force is feeble or evanescent, or permanent polarity where it is strong; that magnets reciprocally affect the intensity and direction of currents, and produce or arrest them.

576. The body of these and like phenomena, and the exposition of the laws which govern them, constitute that branch of electrical science which has been denominated *electro-magnetism.*

Without entering into the somewhat complicated details of this part of voltaic electricity, it will be sufficient here to notice some of the most important phenomena which have been developed in it.

577. If a conducting wire be formed into a spiral or helix such as is represented in *figs.* 313, 314., and be either suspended on points y and y', as shown in *fig.* 313., or made to float upon a

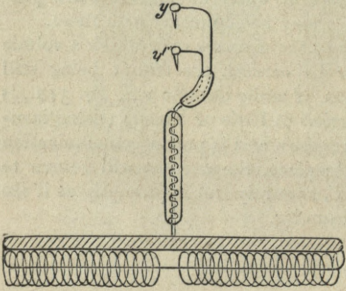

Fig. 313.

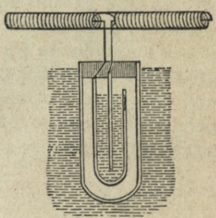

Fig. 314.

liquid, as in *fig.* 314., so that it is capable of revolving in obedience to any force impressed on it, it will be found that the spiral wire will be endowed with all the properties of a magnet so long as the voltaic current is transmitted through it. Thus it will turn till one end is presented to the north and the other to the south, exactly as a compass needle would.

578. If a wire covered with silk so as to prevent the escape of electricity from it, be coiled round a rod of soft iron, such rod will be rendered magnetic so long as a voltaic current is transmitted along the wire. Thus the rod will attract a piece of iron, and will have the directive properties of a compass needle so long as the current continues to flow round it upon the spiral coil; but the moment that the current is suspended, the soft iron instantaneously loses all its magnetic properties.

579. This method of imparting magnetism to iron by the proximity of a voltaic current, is called *electro-magnetic induction.*

580. The property enjoyed by soft iron, of suddenly acquiring magnetism, and as suddenly losing its magnetism, has supplied the means of producing the temporary magnets which are known under the name of *electro-magnets.*

The most simple form of electro-magnet consists of a bar of soft iron bent into the form of a horse shoe, and of a wire wrapped with silk, which is coiled first on one arm, proceeding from one extremity to the bend of the horse shoe, and then upon the other from the bend to the other extremity; care being taken that the convolutions of the spiral shall follow the same direction in passing from one leg to the other. An armature is applied to the ends of the horse shoe, which will adhere to them so long as a voltaic current flows upon the wire, but which will drop off the moment that such current is discontinued.

581. The property of electro-magnets, by which they are capable of suddenly acquiring and losing the magnetic force, has supplied the means of obtaining a mechanical agent which may be applied as a mover of machinery.

Two electro-magnets, such as those represented in *fig.* 315, are placed so that when the electric current is suspended they will rest at a certain distance asunder, and when the current passes on the wire they will be drawn into contact by their mutual attraction. When the current is again suspended they will separate. In this manner, by alternately suspending and transmitting the current on the wire which is coiled round the electro-magnet, the magnet and its armature, or the two magnets, receive an alternate motion to and from each other similar to that of the piston of a steam engine, or the foot of a person who works the treddle of a lathe. This alternate motion is made to produce one of continued rotation by the same mechanical expedients as are used in the application of any other moving power.

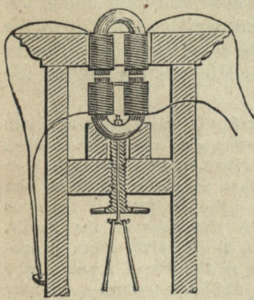

Fig. 315.

The force with which the electro-magnet and its armature attract each other determines the power of the electro-motive machine, just as the pressure of steam on the piston determines the power of a steam engine. This force, when the magnets are given, varies with the nature and magnitude of the galvanic pile which is employed.

582. When a voltaic current passes over a magnetic needle freely suspended, it will deflect the needle from its position of rest, the quantity of this deflection depending on the force, and its direction on the direction of the current.

The needle, when not deflected by the current, will place itself in the magnetic meridian. If, in this case, the wire conducting the current be placed over and parallel to the needle, the poles will be subject at once to two forces; the directive force tending to keep them in the magnetic meridian, and the deflecting force of the current tending to place them at right angles to that meridian. They will, consequently, take an intermediate direction, which will depend on the relation between the directive and deflecting forces. If the latter exceed the former, the needle will incline more to the magnetic east and west; if the former exceed the latter, it will incline more to the magnetic north and south. If these forces be equal, it will take a direction at an angle of 45° with the magnetic meridian. The north pole of the needle will, in all cases, be deflected to the left of the current.

If while the directive force of the needle remains unchanged the intensity of the current vary, the needle will be deflected at a greater or less angle from the magnetic meridian, according as the intensity of the current is increased or diminished.

583. It may happen that the intensity of the current is so feeble, as to be incapable of producing any sensible deflection even on the most sensible needle. The presence of such a current may, nevertheless, be detected, and its intensity measured, by carrying the wire conducting it first over and then under the needle, so that each part of the current shall exercise upon the needle a force tending to deflect it in the same direction. By this expedient the deflecting force exercised by the current on the needle is doubled.

Such an arrangement is represented in *fig.* 316. The wire passes from *n* to *z* over, and from *y* to *x* under the needle; and it is evident, from what has been explained, that the part *z n* and the part *y x* exercise deflecting forces in the same direction on the poles of the needle, both tending to deflect the north or austral pole *a* to the left of a person who stands at *z* and looks towards *n*. It may be shown in like manner that the vertical parts of the current *g x* and *y z* have the same tendency to deflect the north pole *a* to the left of a person viewing it from *z*.

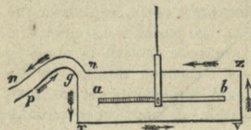

Fig. 316.

The same expedient may be carried further. The wire upon which the current passes may be carried any number of times round the needle, and each successive coil will equally augment its deflecting force. The deflecting force of the simple current will thus be multiplied by twice the number of coils. If the needle be surrounded with a hundred coils of conducting wire, the force which deflects it from its position of rest will be two hundred times greater than the deflecting force of the simple current.

The wire conducting the current must in such case be wrapped with silk or other nonconducting coating, to prevent the escape of the electricity from coil to coil.

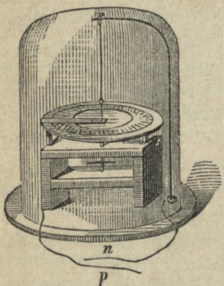

Fig. 317.

Such an apparatus has been called a *multiplier*, in consequence of thus multiplying the force of the current. It has been also denominated a *galvanometer*, inasmuch as it supplies the means of measuring the force of the galvanic current.

We give it by preference the name *reoscope* or *reometer*, as indicating the presence and measuring the intensity of the current.

To construct a *reometer*, let two flat bars of wood or metal be united at the ends, so as to leave an open space between them of sufficient width to allow the suspension and play of a magnetic needle. Let a fine metallic wire of silver or copper, wrapped with silk and having a length of eighty or a hundred feet, be coiled longitudinally round these bars, leaving at its extremities three or four feet uncoiled, so as to be conveniently placed in connection with the poles of the voltaic apparatus from which the current proceeds. Over the bars on which the conducting wire is coiled, is placed a dial, upon which an index plays, which is connected with the magnetic needle suspended between the bars, and which has a common motion with it, the direction of the index always coinciding with that of the needle. The circle of the dial is divided into 360°, the index being directed to 0° or 180°, when the needle is parallel to the coils of the conducting wire.

Such an instrument, mounted in the usual manner and covered by a bell glass to protect it from the disturbance of the air, is represented in *fig.* 317.

CHAP. XVIII.

THERMO-ELECTRICITY.

584. If a piece of metal B, *fig.* 318., or other conductor, be interposed between two pieces, C, of a different metal, the points of contact being reduced to different temperatures, the natural electricity at these points will be decomposed, the positive fluid passing in one direction, and the negative fluid in the other. If the extremities of the pieces C be connected by a wire, a constant current will be established along such wire. The intensity of this current will be invariable so long as the temperatures of the points of contact of B with C remain the same; and it will in general be greater, the greater the difference of these temperatures. If the temperatures of the points of contact be rendered equal, the current will cease.

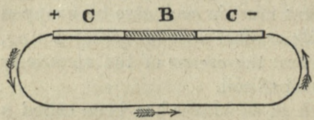

Fig. 318.

These facts may be verified by connecting the extremities of C with the wires of any reoscopic apparatus. The moment a difference of temperature is produced at the points of contact, the needle of the reoscope will be deflected; the deflection will increase or diminish with every increase or diminution of the difference of the temperatures; and if the temperatures be equalised, the needle of the reoscope will return to its position of rest, no deflection being produced.

585. A current thus produced is called a *thermo-electric current.*

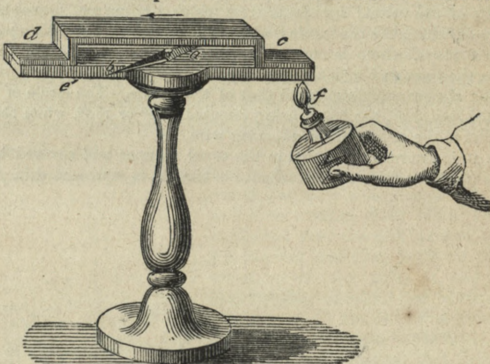

Fig. 319

Those which are produced by the ordinary voltaic arrangements are called for distinction *hydro-electric currents*, a liquid conductor always entering the combination.

A convenient and simple apparatus for the experimental illustration of a thermo-electric current is represented in *fig.* 319. A narrow strip of copper *c d* is bent into a rectangular form, and soldered at both ends to a plate of bismuth *e e'*. A magnetic needle *a b* moves freely on its pivot within the rectangle. The apparatus is so placed, that its vertical plane coincides with that of the magnetic meridian; and the needle, when undisturbed by the current, is at rest in the same direction.

Now, if a lamp *f* be applied to one end *e* of the plate of bismuth, so as to raise its temperature above that of the other end, the needle will be immediately deflected, and the deflection will increase as the difference of the temperatures of the ends of the plate of bismuth is increased. If the end *e* of the bismuth be cooled to a temperature below that of the surrounding atmosphere, the needle will be deflected the other way, showing that the direction of the current has been reversed. And by repeating the same experiments with the other end *e'*, these results will be confirmed.

586. When the temperature of the end *e* of the bismuth is more elevated than that of the end *e'*, the north pole of the needle is deflected to the left of a person standing at the end *e*, from which it appears that the current flows round the rectangle in the direction represented by the arrow.

If cold be applied to the end *e*, the needle will be deflected to the right, showing that the direction of the current will be reversed, the positive fluid always flowing towards the warmer end of the bismuth.

587. If means be taken to maintain the extremities of the bismuth at a constant difference of temperature, the needle will maintain a constant deflection. Thus, if one end of the bismuth be immersed in boiling water and the other in melting ice, so that their temperatures shall be constantly maintained at 212° and 32°, the deflection of the needle will be invariable. If the temperature of the one be gradually lowered, and the other gradually raised, the deflection of the needle will be gradually diminished; and when the temperatures are equalised, the needle will resume its position in the magnetic meridian.

588. This property, in virtue of which a derangement of the electric equilibrium attends a derangement of the thermal equilibrium, is common to all the metals, and, indeed, to conductors generally; but, like other physical properties, they are endowed with it in very different degrees. Among the metals, bismuth and antimony have the greatest thermo-electric energy, whether they are placed in contact with each other, or with any other metal. If a bar of either of these metals be placed with its extremities in contact with the wires of a reometer, a deflection of the needle will

be produced by the mere warmth of the finger applied to one end of the bar. If the finger be applied to both ends, the deflection will be redressed, and the needle will return to the magnetic meridian.

It has been ascertained that if different parts of the same mass of bismuth or antimony be raised to different temperatures, the electric equilibrium will be disturbed, and currents will be established in different directions through it, depending on the relative temperatures. These currents are, however, much less intense than in the case where the derangement of temperature is produced at the points of contact or junction of different conductors.

CHAP. XIX.

ELECTRO-CHEMISTRY.

589. When a voltaic current of sufficient intensity is made to pass through certain bodies consisting of constituents chemically combined, it is found that decomposition is produced attended by peculiar circumstances and conditions. The compound is resolved into two constituents, which appear to be transported in contrary directions, one *with* and the other *against* the course of the current. The former is disengaged at the place where the current leaves, and the other at the place where it enters, the compound.

All compounds are not resolvable into their constituents by this agency, and those which are, are not equally so; some being resolved by a very feeble current, while others yield only to one of extreme intensity.

590. Bodies which are capable of being decomposed by an electric current have been called *electrolytes*, and decomposition thus produced has been denominated *electrolysis*.

591. To render electrolysis practicable, the molecules of the electrolyte must have a perfect freedom of motion amongst each other. The electrolyte must therefore be liquid. It may be reduced to this state either by solution or fusion.

592. To render intelligible the process of electrolysis, let us take the example of water, the first substance upon which the decomposing power of the pile was observed. Water is a binary compound, whose simple constituents are the gases called oxygen and hydrogen. Nine grains' weight of water consist of eight grains of oxygen and one grain of hydrogen.

The specific gravity of oxygen being sixteen times that of hydrogen, it follows that the volumes of these gases which compose water are in the ratio of two to one; so that a quantity of water which contains as much oxygen as, in the gaseous state, would have the volume of a cubic inch, contains as much hydrogen as would, under the same pressure, have the volume of two cubic inches.

The combination of these gases, so as to convert them into water, is determined by passing the electric spark taken from a common machine through a mixture of them. If eight parts by weight of oxygen and one of hydrogen, or, what is the same, one part by measure of oxygen and two of hydrogen, be introduced into the same receiver, on passing through them the electric spark an explosion will take place; the gases will disappear, and the receiver will be filled first with steam, which being condensed, will be presented in the form of water. The weight of water contained in the receiver will be equal precisely to the sum of the weight of the two gases.

These being premised, the phenomena attending the electrolysis of water may be easily understood.

593. Let a glass tube, closed at one end, be filled with water slightly acidulated, and, stopping the open end, let it be inverted and immersed in similarly acidulated water contained in any open vessel. The column in the tube will be sustained there by the atmospheric pressure, as the mercurial column is sustained in a barometric tube; but in this case the tube will remain completely filled, no vacant space appearing at the top, the height of the column being considerably less than that which would balance the atmospheric pressure. Let two platinum wires be connected with the poles of a voltaic pile, and let their extremities, being immersed in the vessel containing the tube, be bent so as to be presented upwards in the tube without touching each other. Immediately small bubbles of gas will be observed to issue from the points of the wires, and to rise through the water and collect in the top of the tube, and this will continue until the entire tube is filled with gas, by the pressure of which the water will be expelled from it. If the tube be now removed from the vessel, and the gas be transferred to a receiver, so arranged that the electric spark may be transmitted through it, on such transmission the gas will be reconverted into water.

The gases, therefore, evolved at the points of the wires, which in the exposition of the phenomena of electrolysis are termed the *electrodes*, are the constituents of water; and since they cannot combine to form water, except in the definite ratio of 1 to 2 by measure, they must have been evolved in that exact proportion at the electrodes.

594. The decomposing power of the voltaic current had not long been known before it became, in the hands of Sir H. Davy and his successors, the means of resolving the alkalis and earths, before that time considered as simple bodies, into their constituents. This class of bodies was shown to be oxidised metals. When submitted to such conditions as enabled a strong voltaic current to pass through them, oxygen was liberated at the positive electrode, and the metallic base appeared at the negative electrode.

595. A new series of metals was thus discovered, which received names derived from those of the alkalis and earths of which they formed the bases. Thus, the metallic base of potash was called *potassium*, that of soda *sodium*, that of lime *calcium*, that of silica *silicium*, and so on.

In many cases it is difficult to maintain those metals in their simple state, owing to their strong affinity for oxygen. Thus potassium, if exposed to the atmosphere at common temperatures, enters directly into combination with the air, and burns. When it is desired to collect and preserve it in the metallic state it is decomposed by the current in contact with mercury, with which it enters into combination, forming an amalgam. It is afterwards separated by distillation from the mercury, and preserved in the metallic state under the oil of naphtha, in a glass tube hermetically closed, the air being previously expelled.

CHAP. XX.

ELECTRO-METALLURGY

596. The decomposing power of the voltaic current applied to solutions of the salts and oxides of metals has supplied various processes to the industrial arts, which inventors, improvers, and manufacturers have denominated galvano-plastic, electro-plastic, galvano-type, electrotype, and electro-plating and gilding. These processes and their results may be comprehended under the more general denomination, *Electro-metallurgy*.

597. If a current of sufficient intensity be transmitted through a solution of a salt or oxide, having a metallic base, it will be understood, from what has been already explained, that while the oxygen or acid is developed at the positive electrode, the metal will be evolved either by the primary or secondary action of the current of the negative electrode, and being in the nascent state, will have a tendency to combine with it, if there be an affinity, or to adhere to it by mere cohesion, if not.

598. The bodies used as electrodes must be *superficially* con-

ductors, since otherwise the current could not pass between them; but subject to this condition, they may have any material form or magnitude which is compatible with their immersion in the solution. If the body be metallic, its surface has necessarily the conducting property. If it be formed of a material which is a non-conductor, or an imperfect conductor, the power of conduction may be imparted to its surface by coating it with finely powdered black lead and other similar expedients. This process is called *metallising* the surface.

599. By the continuance of the process of decomposition the solution will be rendered gradually weaker, and the deposition of the metal would go on more slowly. This inconvenience is remedied by using, as the positive electrode, a plate of the same metal, which is to be deposited on the negative electrode. The acid or oxygen liberated in the decomposition, in this case, enters into combination with the metal of the positive electrode, and produces as much salt or oxide as is decomposed at the other electrode, which salt or oxide being dissolved as fast as it is formed, maintains the solution at a nearly uniform degree of strength.

600. The state of the metal disengaged at the negative electrode depends on the intensity of the current, the strength of the solution, its acidity, and its temperature, and the regulation of these conditions in each particular case will require much practical skill on the part of the operator, since few general rules can be given for his direction.

In the case, for example, of a solution of one of the salts of copper, a feeble current will deposit on the electrode a coating of copper so malleable that it may be cut with a knife. With a more intense current the metal will become harder. As the intensity of the current is gradually augmented, it becomes successively brittle, granulous, crystalline, rough, pulverulent, and in fine loses all cohesion,—practice alone will enable the operator to observe the conditions necessary to give the coating deposited on the electrode the desired quality.

601. It is in all cases desirable, and in many indispensable, that the metallic coating deposited on the electrode shall have an uniform thickness. To insure this, conditions should be established which will render the action of the current on every part of the surface of the electrode uniform, so that the same quantity of metal may be deposited in the same time. Many precautions are necessary to attain this object. Both electrodes should be connected at several points with the conductors, which go to the poles of the battery, and they should be presented to each other so that the intermediate spaces should be as nearly as possible equal, since the intensities of the currents between point and point vary with the distance. The deposition of the metal is also much in-

fluenced by the form of the body. It is in general more freely made on the salient and projecting parts, than in those which are sunk.

602. If the body on which the metallic deposit is made be one which is liable to absorb the solution, a coating of some substance must be previously given to it which shall be impervious to the solution.

603. When a part only of a metallic or other conducting body is desired to be coated with the metallic deposit, all the parts immersed not intended to be so coated are protected by a coating of wax, tallow, or other nonconductor.

604. The most extensive and useful application of these principles in the arts is the process of gilding and silvering articles made of the baser metals.

The article to be coated with gold being previously made clean, is connected with the negative pole of the battery, while a plate of gold is connected with its positive pole. Both are then immersed in a bath consisting of a solution of the chloride of gold and cyanide of potassium, in proportions which vary with different gilders. Practice varies also as to the temperature and the strength of the solution. The chloride is decomposed, the metallic base being deposited as a coating on the article connected with the negative pole, and the chloride combining with a corresponding portion of the gold connected with the positive pole, and reproducing the chloride which is dissolved in the bath as fast as it is decomposed, thus maintaining the strength of the solution.

A coating of silver, copper, cobalt, nickel, and other metals is deposited by similar processes.

605. When the article on which the coating is deposited is metallic, the coating will in some cases adhere with great tenacity. In others, the result is less satisfactory; as, for example, where gold is deposited on iron or steel. In such cases the difficulty may be surmounted by first coating the article with a metal which will adhere to it, and then depositing upon this the definite coating.

606. The extreme tenuity with which a metallic coating may be deposited by such processes, supplies the means of imparting to various objects of art the external appearance and qualities of any proposed metal, without impairing in the slightest degree their most delicate forms and lineaments. The most exquisitely moulded statuette in plaster may thus acquire all the appearance of having been executed in gold, silver, copper, or bronze, without losing any of the artistic details on which its beauty depends.

607. If it be desired to produce a metallic mould of any object, it is generally necessary to mould it in separate pieces, which being afterwards combined, a mould of the whole is obtained.

That part intended to be moulded is first rubbed with sweet oil, black lead, or some other lubricant, which will prevent the metal deposited from adhering to it, without separating the mould from the surface, in so sensible a degree as to prevent the perfect correspondence of the mould with the original. All that part not intended to be moulded is invested with wax or other material, to intercept the solution. The object being then immersed, and the electrolysis established, the metal will be deposited on the exposed surface. When it has attained a sufficient thickness the object is withdrawn from the solution, and the metallic deposit detached. It will be found to exhibit, with the utmost possible precision, an impression of the original. The same process being repeated for each part of the object, and the partial moulds thus obtained being combined, a metallic mould of the whole will be produced.

608. To reproduce any object in metal it is only necessary to fill the mould of it, obtained by the process above explained, with the solution of the metal of which it is desired to form the object, the surface of the mould being previously prepared, so as to prevent adhesion. The solution is then put in connection with the positive pole of the pile, while the mould is put in connection with the negative pole. The metal is deposited on the mould, and when it has attained the necessary thickness the mould is detached, and the object is obtained.

In general, however, it is found more convenient to mould the object to be reproduced in metal by the ordinary processes in wax, plaster of paris, or fusible alloy. When they are made in wax, plaster, or any nonconducting material, their inner surfaces must be rubbed with black lead, to give them the conducting power. When the deposit is made of the necessary thickness, the mould is broken off or otherwise detached.

Statues, statuettes, and bas-reliefs in plaster can thus be reproduced in metal with the greatest facility and precision, at an expense not much exceeding that of the metal of which they are formed.

609. A mould in plaster of paris, wax, or gutta percha, being taken from a wood engraving or a stereotype plate, a stereotype may be obtained from the mould by the processes above described. The pages now before the reader have been stereotyped by this process.

Copper or steel engraved plates may be multiplied by like methods. A mould is first taken, which exhibits the engraving in relief. A metallic plate deposited upon this by the electrolytic process will reproduce the engraved plate.

610. The electro-metallurgic processes have been extended by ingenious contrivances to other substances besides metal. Thus a coating of metal may be deposited on cloth, lace, or other woven fabrics, by various ingenious expedients, of which the following is an example: —

On a plate of copper attach smoothly a cloth of linen, cotton, or wool, and then connect the plate with a negative pole of a voltaic battery, immerse it in a solution of the metal with which it is to be coated, and connect a piece of the same metal with the positive pole; decomposition will then commence, and the molecules of metal, as they are separated from the solution, must pass through the cloth in advancing to the copper to which the cloth is attached. In their passage through the cloth they are more or less arrested by it. They insinuate themselves into its pores, and, in fine, form a complete metallic cloth. Lace is metallised in this way by first coating it with plumbago, and then subjecting it to the electro-metallurgic process.

Quills, feathers, flowers, and other delicate fibrous substances may be metallised in the same way. In the case of the most delicate of these the article is first dipped into a solution of phosphorus and sulphate of carbon, and is well wetted with the liquid. It is then immersed in a solution of nitrate of silver. Phosphorus has the property of reviving silver and gold from their solutions. Consequently, the article is immediately coated with a very attenuated fibre of the metal.

A form of apparatus commonly used is represented in *fig.* 320., where A is a brass rod, supported by hooks 1, 2, 3, 4, on the edge of a large cylindrical vessel of glass or porcelain. One of these hooks, 3, supports a vertical rod *a*, on which there is a metallic ball pierced horizontally, in which a conducting rod N is held by the tightening screw *b*.

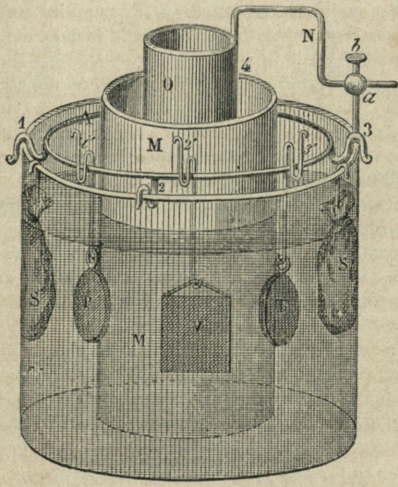

Fig. 320.

Supposing the deposit required is copper, the solution of the sulphate of copper is poured into the vessel. In this vessel is immersed a smaller cylindrical vessel M N of unglazed porcelain filled with acidulated water, in which a cylinder O of amalgamated zinc connected with N is plunged.

Let small bags S S, filled with crystals of the sulphate of copper, be suspended upon the edge of the vessel and immersed in the solution so that as the solution is weakened by decomposition, these crystals shall be dissolved and restore its strength.

Let the objects P V T, &c., upon which the copper is to be deposited, be now suspended upon the ring A by metallic rods: a complete voltaic combination will thus be formed, since the copper electrodes P V T, &c., will be in metallic connection by the ring A, the rod *a*, and the conductor N, with the zinc cylinder O; so that the whole will form a single pair on

Daniel's system (565.). This being done, the decomposition of the solution will proceed, copper will be deposited upon P V T, &c., and the strength of the solution will be restored by the dissolution of the copper crystals in the bags S, S.

CHAP. XXI.

ELECTRO-TELEGRAPHY.

611. Of all the applications of electric agency to the uses of life, that which is transcendently the most admirable in its effects, and the most important in its consequences, is the electric telegraph. No force of habit, however long continued, no degree of familiarity, can efface the sense of wonder which the effects of this most marvellous application of science excite.

The electric telegraph, whatever form it may assume, derives its efficiency from the three following conditions:—

1. A power to develop the electric fluid continuously, and in the necessary quantity.

2. A power to convey it to any required distance without being injuriously dissipated.

3. A power to cause it, after arriving at such distant point, to make written or printed characters, or some sensible signs serving the purpose of such characters.

The apparatus from which the moving power by which these effects are produced is derived, is the voltaic pile. This is to the electric telegraph what a boiler is to a steam engine. It is the generator of the fluid by which the action of the machine is produced and maintained.

We have therefore first to explain how the electric fluid generated in the apparatus just explained, can be transmitted to a distance without being wasted or dissipated in an injurious degree *en route*.

If tubes or pipes could be constructed with sufficient facility and cheapness, through which the subtle fluid could flow, and which would be capable of confining it during its transit, this object would be attained. As the galvanic battery is analogous to the boiler, such tubes would be analogous in their form and functions to the steam pipe of a steam engine.

612. If a wire, coated with a nonconducting substance capable of resisting the vicissitudes of weather, were extended between any two distant points, one end of it being attached to one of the extremities of a galvanic battery, a stream of electricity would pass along the wire —*provided the other end of the wire were connected by a conductor with the other extremity of the battery.*

To fulfil this last condition, it was usual, when the electric telegraphs were first erected, to have a second wire extended from the distant point back to the battery in which the electricity was generated. But it was afterwards discovered that the *earth itself* was the best, and by far the cheapest and most convenient, conductor which could be used for this returning stream of electricity.

Instead, therefore, of connecting the poles of the battery by a second wire, they are connected respectively with the earth by two independent wires, so that the returning current is first transmitted to the earth, and through the earth to a corresponding wire at the distant station, to which a telegraphic communication is made.

This arrangement will be more readily understood by reference to *fig.* 312. If P be the point from which the current is transmitted, it will pass along the wire to a plate of metal E, five or six feet square, buried in the earth, from whence it will pass through the earth, as indicated by the arrows, to another plate of metal E′, and from thence, by the wire to the negative pole N of the battery.

In the arrangement, as here represented, the current is transmitted through the wire and the earth from the positive to the negative pole of the same battery. But the effects will be precisely the same if P be imagined to represent the positive pole of a battery at any one station, and N the negative pole of a different battery at any other station, however distant; provided only that the negative pole of the former battery be connected with the positive pole of the latter by a wire, or series of wires, or any other continuous conductors.

It has not been found necessary in practice to wrap the wires with silk, or to case them with any other nonconductor. They usually consist of iron, which is recommended at once by its strength and cheapness, and are coated with zinc, the better to resist oxidation, by the galvanic process.

The wires thus prepared are usually suspended on posts from fifteen to thirty feet high, and at intervals of about sixty yards, which is at the rate of about thirty to a mile.

To each of these poles are attached as many tubes or rollers of porcelain or glass as there are wires to be supported (*fig.* 321.). Each wire passes through a tube, or is supported on a roller; and the material of the tubes or rollers

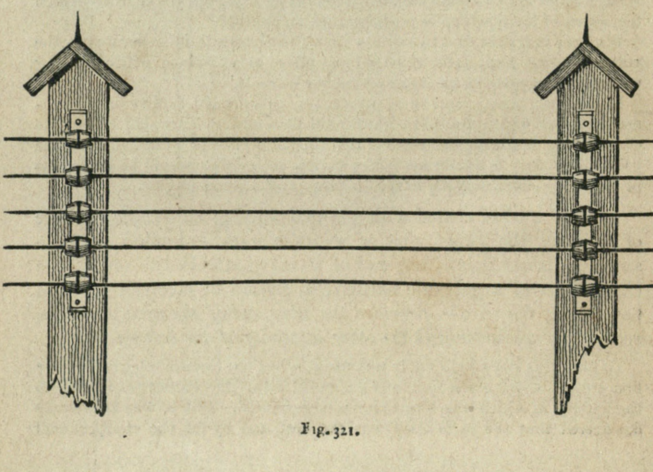

Fig. 321.

being among the most perfect of the class of nonconducting substances, the escape of the electricity at the point of contact is prevented.

613. Although the mode of carrying the conducting wires at a certain elevation on supports above the ground, has been the most general mode of construction adopted on telegraphic lines, it has been found in certain localities subject to difficulties and inconvenience, and some projectors have considered that in all cases it would be more advisable to carry the conducting wires under ground.

This underground system has been adopted in the streets of London, and of some other large towns. The English and Irish Magnetic Telegraph Company have adopted it on a great extent of their lines, which overspread the country. The European Submarine Telegraph Company has also adopted it on the line between London and Dover, which follows the course of the old Dover mail-coach road by Gravesend, Rochester, and Canterbury.

614. The current being by these means transmitted instantaneously from any station to another, connected with it by such conducting wires, it is necessary to select, among the many effects which it is capable of producing, such as may be fitted for telegraphic signs.

There are a great variety of properties of the current which supply means of accomplishing this. If it can be made to affect any object in such a manner as to cause such object to produce any effect sensible to the eye, the ear, or the touch, such effect may be used as a *sign;* and if it be capable of being *varied*, each distinct *variety* of which it is susceptible may be adopted as a *distinct sign*. Such signs may then be taken as signifying the letters of the alphabet, the digits composing numbers, or such single words as are of most frequent occurrence.

The rapidity and precision of the communication will depend on the rate at which such signs can be produced in succession, and on the certainty and accuracy with which their appearance at the place of destination will follow the action of the producing cause at the station from which the despatch is transmitted.

These preliminaries being understood, it remains to show what effects of the electric current are available for this purpose.

These effects are: —

I. The power of the electric current to deflect a magnetic needle from its position of rest.

II. The power of the current to impart temporary magnetism to soft iron.

III. The power of the current to decompose certain chemical solutions

These methods of producing signs at a distance have been severally used for telegraphic purposes by different inventors and in different countries. In the form of telegraph most commonly used in England, a magnetic needle, suspended vertically, is capable of being turned to the right or left by the transmission of a voltaic current behind it, this current being produced by an operator at a distant station, and the signs consist of a certain number of successive deflections of the needle to the right and to the left. In *fig.* 322. is presented a view of this instrument in outline, showing the number of deflections to the right or to the left, by which each letter and number is signified.

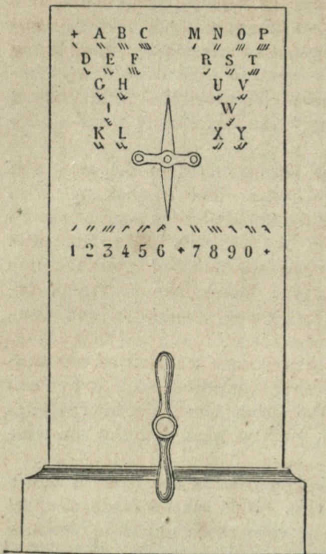

Fig. 322.

615. In the telegraph of Morse, generally used in the United States, the second method of producing signs, mentioned above, is adopted. A voltaic current transmitted from a distant station is made to impart momentary magnetism to a piece of soft iron, by which a lever, armed with a point or style, is attracted against a band of paper moving under it, which it punctures, and the letters and numbers are expressed by different numbers of these punctures made in the band of paper.

616. In the electro-chemical telegraphs the current is transmitted from a distance through a metallic style, which passes upon a paper moved under it, and impregnated with a chemical solution capable of being decomposed by the current. When decomposed a coloured spot or line is made upon the paper, and by alternately maintaining and interrupting the current, spots and lines at different intervals, or at different lengths, are traced upon the paper by an operator at a distance.

CHAP. XXII.

ELECTRO-ILLUMINATION.

617. Of all the luminous effects produced by the agency of electricity, by far the most splendid is the light produced by the passage of the current, proceeding from a powerful battery,

between two pencils of hard charcoal presented point to point. The charcoal being an imperfect conductor is rendered incandescent by the current, and being infusible at any temperature hitherto attained, the degree of splendour of which its incandescence is susceptible has no other practical limit except the power of the battery.

The charcoal best adapted for this experiment is that which is obtained from the residuum of the coke in retorts of gas works. This is hardened and formed into pencil-shaped pointed cylinders, from two to four inches in length, and mounted as represented in *fig.* 323., where *p* and *n*, the two metallic pencil holders, are in metallic connection with the poles of the pile, and so mounted that the charcoal pencils fixed in them can at pleasure be made to approach each other until their points come into contact, or to recede from each other to any necessary distance. When they are brought into contact, the current will pass between them, and the charcoal will become intensely luminous. When separated to a short distance, a splendid flame will pass between them of the form represented in *fig.* 324. It will be observed that the form of the flame is not symmetrical with relation to the two poles, the part next the positive point having the greatest diameter, and the diameter becoming gradually less in approaching the negative point.

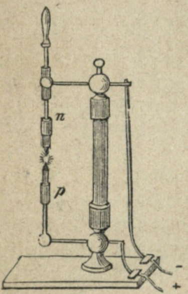

Fig. 323.

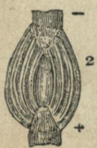

Fig. 324.

618. It would be a great error to ascribe the light produced in charcoal pencils to the combustion of that substance. None of the consequences or effects of combustion attend the phenomena, no carbonic acid is produced, nor does the charcoal undergo any diminution of weight save a small amount due to mere mechanical causes. On the contrary, at the points where the calorific action is most intense, it becomes more hard and dense. But what negatives still more clearly the supposition of combustion is, that the incandescence is still more intense in a vacuum, or in any of the gases that do not support combustion, than in the ordinary atmosphere.

Peschel states that, instead of two charcoal pencils, he has laid a piece of charcoal, or well burnt coke, upon the surface of mercury, connected with one pole of the battery, while he has touched it with a piece of platinum connected with the other pole. In this manner he obtained a light whose splendour was intolerable to the eye.

619. M. Foucault first applied the electric light produced by charcoal pencils as a substitute for the lime light in the gas microscope.

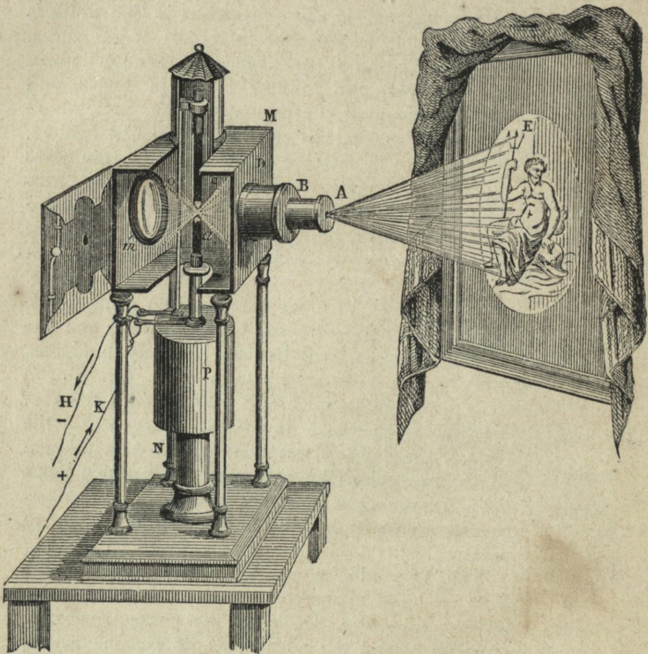

Fig. 325.

This apparatus, in the form in which it is now constructed by M. Dubosc of Paris, is represented in *fig.* 325. M. Dubosc has applied to his photo-electric microscope a self-adjusting apparatus, by which the light is maintained with a nearly uniform brilliancy, notwithstanding the gradual waste of the charcoal. This is accomplished by an electro-magnet, by which the current is re-established, whenever it has a tendency to be suspended.

CHAP. XXIII.

MEDICAL ELECTRICITY.

620. ELECTRIC excitation has been tried as a curative agent for various classes of maladies from the date of the discovery of the Leyden jar. Soon after the discovery of galvanism, Galvani himself proposed it as a therapeutic agent; but although a great number of scientific practitioners in different countries have devoted themselves to the investigation of its effects, there still remains much doubt, not only as to its curative influence, but as to the classes of maladies to which it may be with advantage applied, and even as to its mode of application. It appears, however, to be generally admitted that voltaic electricity is much better fitted for medical purposes than common electricity, and that of the different forms of voltaic electricity, intermitting currents produced by induction are in general to be preferred to the immediate currents produced by the battery. It is even maintained by practitioners who have more especially devoted themselves to the study of its effects, that different induced currents have different therapeutic properties.

621. Duchenne's electro-voltaic apparatus consists of a bobbin wrapped with coils of wire.

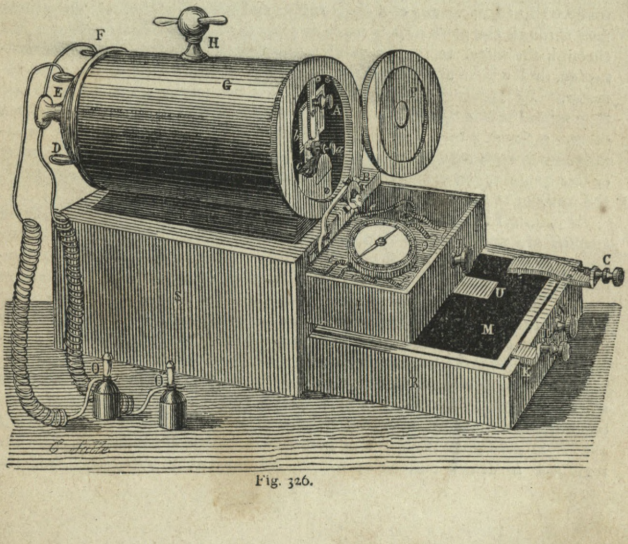

Fig. 326.

This bobbin is enclosed in a brass tube, G, *fig.* 326. The apparatus is fixed upon a mahogany case containing two drawers. The first contains a compass needle mounted as a reometer, and serving to measure the intensity of the primary current. The second contains in a compact form a charcoal battery. The zinc element M has itself the form of the drawer, and contains a solution of sea salt, and a rectangular piece U made of the charcoal of coke well calcined and prepared in the same manner as for Bunsen's battery. In the central part of the charcoal is a little cavity, in which a small quantity of nitric acid is poured, which is immediately absorbed. Two ribbons of copper proceeding from the poles of the battery are connected with the buttons L and N attached to the front of the drawer. The first of these L is connected with the zinc end of the battery, and represents the negative pole; and the second is connected with the charcoal end, and represents the positive pole.

When the drawers are closed, the buttons L and N are put in connection with two pieces connected with the arrangement combined within the cylinder G. One of these pieces is movable, so that the circuit can be closed and broken at pleasure.

The induced current is produced only at the moments when the primary current commences and terminates. It is, therefore, necessary that the latter current should be subject to continued intermission. In the present apparatus, these intermissions may be rendered at pleasure more or less rapid. To render them rapid, the current passes into a piece of soft iron A, which oscillates very rapidly under the influence of a bundle of soft iron wires placed in the axis of the bobbin, and temporarily magnetised by the current. It is this piece A which, by its alternate motion to and fro, interrupts and re-establishes the primary current, and by that means produces the intermission of the induced current.

To produce a slow intermission of the current, the oscillating piece A is rendered fixed by means of a little rod *b*; and instead of making the current pass through the piece A, it is made to pass through an elastic ribbon *e*, and through the metal teeth of a wooden wheel with which that ribbon is connected, and which appears in the figure above the needle of the galvanometer. By turning a handle provided for the purpose, but which is not represented in the figure, the current is interrupted as often as the ribbon *e* ceases to touch a tooth; and as there are four teeth, there are four intermissions in each revolution, so that the operator, by turning a handle more or less rapidly, can vary at will the rate of intermission, and, consequently, the number of shocks imparted in a given time.

To transmit the shocks, the extremities of the wire conducting the induced current are put in connection with two buttons E and F at the end of the cylinder, and these buttons are themselves connected by means of two conducting wires wrapped with silk, with two exciters having glass handles O O. The operator holding them by the glass handles, and applying their bases to the two parts of the body of the patient, between which he intends to transmit the shock, the desired effect is produced, its intensity being regulated by turning the handle already mentioned.

A regulator is also provided by which the intensity of the current can be varied at will. This consists of a copper cylinder which envelopes the bobbin, and which can be drawn from it more or less, like a drawer, by the aid of a graduated rod. The greatest intensity is produced when the regulator is drawn out, so as to uncover the bobbin altogether, and the minimum when it completely covers it. The effect of this cylindrical cover is explained by the induced currents which are produced in its mass.

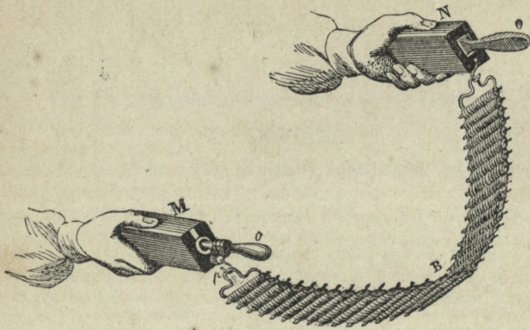

Fig. 327.

622. Pulvermacher's apparatus, which is represented in *fig.* 327., consists of a series of small cylindrical rods of wood, upon which are rolled, one beside the other, without contact however, a wire of zinc and a wire of copper.

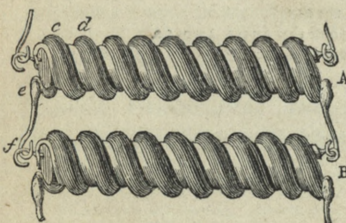

Fig. 328.

One of these rods, with the wires rolled upon it, is shown on a larger scale in *fig.* 328.

At each of its ends the zinc wire *c d*, of the cylinder A, is jointed to the copper wire of the cylinder B by means of two little rings of copper implanted in the wood. The zinc wire of the cylinder B is then connected, in the same manner, with the copper wire of the third cylinder, and so on, so that the zinc of one cylinder always forms, with the copper of the following cylinder, a couple altogether analogous to the arrangement of the ordinary galvanic pile.

THE END.

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