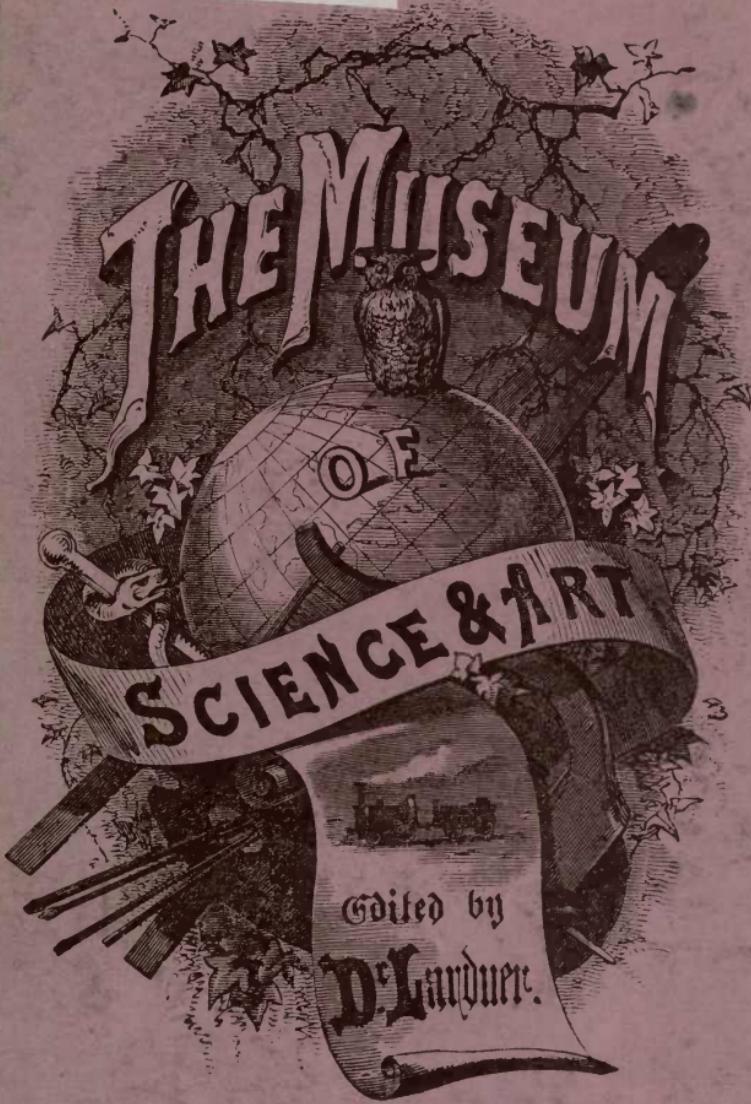


UC-NRLF



B 3 085 198

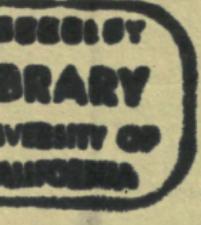


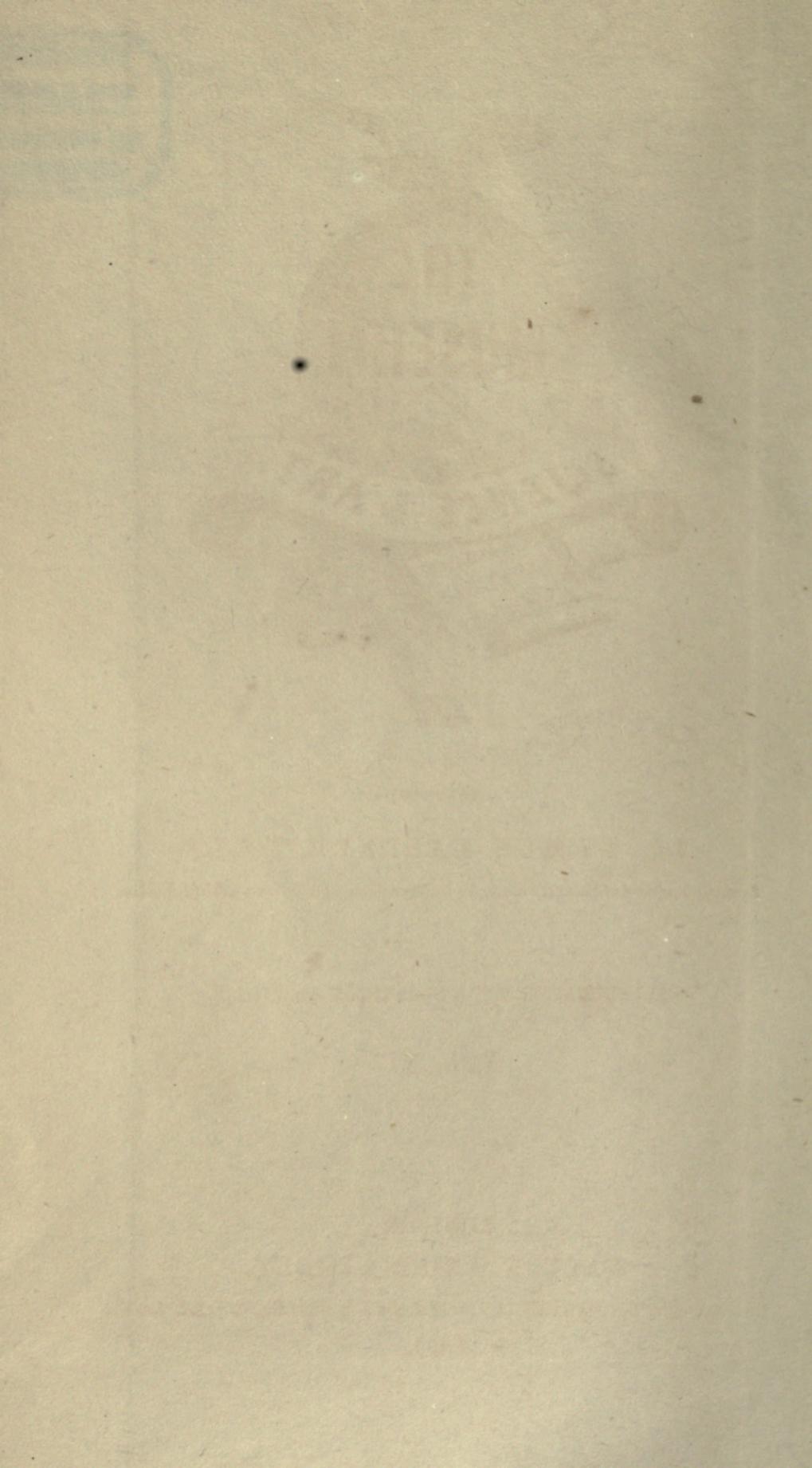
LONDON

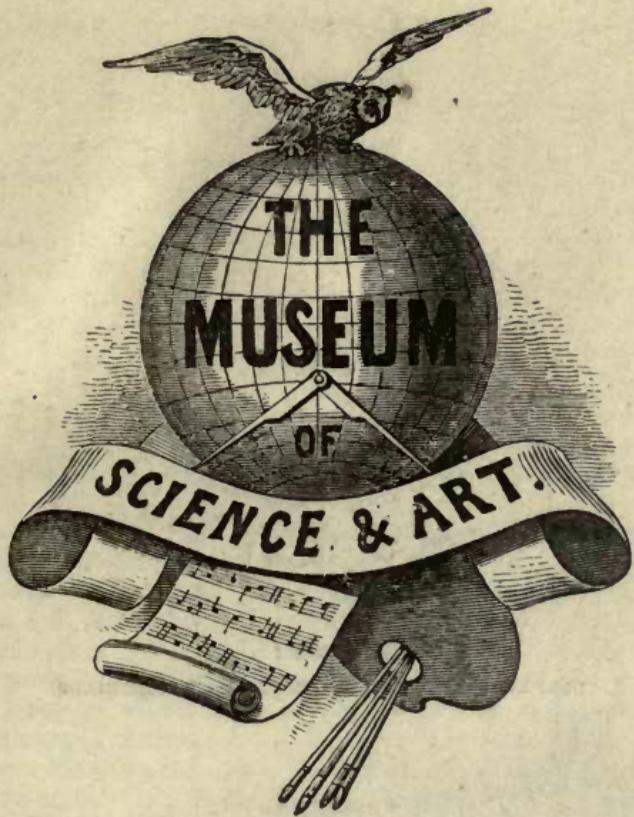
WALTON AND MABERLY,

UPPER GOWER STREET & IVY LANE.

Price Eighteenpence.







EDITED BY

DIONYSIUS LARDNER, D.C.L.,

Formerly Professor of Natural Philosophy and Astronomy in University College, London.

ILLUSTRATED BY ENGRAVINGS ON WOOD.

VOL. VI.

LONDON:

WALTON AND MABERLY,

UPPER GOWER STREET, AND IVY LANE, PATERNOSTER ROW.

1855.

*LOAN STACK

LONDON :
BRADBURY AND EVANS, PRINTERS, WHITEFRIARS.

CONTENTS.

COMMON THINGS—CLOCKS AND WATCHES.

	PAGE
CHAP. I.—1. General want of time measurers.—2. No natural measures for short intervals.—3. Approximative expedient by shadows.—4. Sun-dials.—5. Differently constructed for different places.—6. Earliest sun-dials.—7. Clepsydra, or water-clock.—8. Hour-glass.—9. Mercurial time-gauge.—10. Clocks—their chief parts.—11. Regulating power of the pendulum.—12. Uniform rate of vibration.—13. Analysis of a vibration.—14. Experimental verification of isochronism.—15. Moving power sustains the vibration.—16. Vibration not dependent on weight of pendulum.—17. Time of vibration varies with the length.—18. Analysis of motion of pendulous mass.—19. How the pendulum governs the hands.—20. Produces intermitting motion.—21. Pendulum's motion maintained by moving power	17
CHAP. II.—22. Action of pendulum on escapement wheel.—23. Rate of motion of hands produced by tooth and pinion work.—24. Method of making pinions.—25. Mutual action of toothed wheels.—26. Wheel and pinion.—27. Bevelled and crown wheels.—28. Weight applied as a moving power.—29. Why hands not turned back when clock is wound up.—30. Main-spring.—31. Its power variable.—32. The fusee.—33. Balance-wheel.—34. Its vibrations uniform.—35. General explanation of a watch.—36. Of a clock moved by a weight.—37. Method of regulating the rate	17
CHAP. III.—38. Method of regulating a balance-wheel.—39. Recoil escapement.—40. Cylindrical escapement.—41. Duplex.—42. Lever.—43. Detached.—44. Maintaining power of a clock moved by a weight.—45. Of a watch moved by a main-spring.—46. Weight of mainspring and pendulum and balance-wheel variously combined.—47. Watches and chronometers.—48. Marine chronometers.—49. Stationary chronometers.—50. Striking apparatus	33

MICROSCOPIC DRAWING AND ENGRAVING.

	PAGE
CHAP. I.—1. Beautiful precision of the minute structure of natural objects.—2. Cornea of a fly's eye.—3. Number of eyes of different insects.—4. Astonishing precision of artificial objects.—5. Demand for such objects by Microscopists.—6. Classes of such artificial objects.—7. Microscopic scales.—8. Method of engraving them.—9. Measurement of microscopic objects with them.—10. Their minuteness.—11. Scales of Mr. Froment.—12. Rectangular scales.—13. Micrometric threads.—14. Necessity for microscopic tests.—15. Test-objects.—16. Telescopic tests ; double stars.—17. Nebulae and stellar-clusters.—18. Effects of different telescopes upon them : telescopes of Herschel and Lord Rosse.—19. Remarkable nebulae described by Herschel.—20. Differently seen by Lord Rosse.—21. Microscopic tests.—22. Improved powers of microscope.—23. The Lepisma-Saccharina.—24. The Podura, or Spring-tail	49
CHAP. II.—25. Natural tests not invariable.—26. Natural tests imperfect standards.—27. Nobert's test-plates.—28. The degree of closeness of their lines.—29. Their use.—30. Apparent error respecting them.—31. Froment's microscopic engraving.—32. Method of executing it.—33. Various methods of microscopic drawing.—34. Drawings by squares.—35. Dr. Goring's drawings.—36. Structure and metamorphosis of insects.—37. The day-fly.—38. The larva of this insect.—39. Its organs of respiration.—40. Its general structure.—41. Its mobility.—42. State of chrysalis.—43. The perfect insect.—44. The production and deposition of its eggs, and its death.—45. Death may be delayed by postponing the laying of the eggs.—46. They take no food.—47. Their countless numbers ; their bodies used as manure	65
CHAP. III.—48. The beetle.—49. Its larva.—50. Drawing of it in its natural size.—51. Dr. Goring's magnified drawing.—52. Production of the beetle from the egg.—53. The young larva.—54. Its voracity and manner of seizing its prey.—55. Description of its organs.—56. Its chrysalis.—57. Water-beetle.—58. Gnat.—59. Dr. Goring's method of drawing.—60. Drawing by the camera-lucida.—61. Section of the human skin ; sweating-gland and duct.—62. The itch insect.—63. Method of obtaining it	81
CHAP. IV.—64. Structure of the itch insect.—65. Its habits.—66. The mange insect.—67. Its form and structure.—68. Defects incidental to drawing with the camera.—69. Microscopic photographs.—70. Microscopic daguerreotypes by Messrs. Donné and Foucault.—71. Description of the blood.—72. Red and white corpuscles.—73. Daguerreotype of a drop of blood magnified.—74. Magnitude of the corpuscles.—75. Cause of the redness of	

CONTENTS.

v

	PAGE
blood.—76. Corpuscles of inferior animals.—77. White globules. —78. White grains.—79. White globules converted into red corpuscles.—80. Red corpuscles dissolved.—81. Circulation of the blood.—82. Method of showing it in the tongue of a frog. —83. The arteries distinguishable from the veins.—84. The vascular system of the tongue.—85. Mucous glands.—86. Milk ; its constitution.—87. Magnified view of a drop of milk.— 88. The butter globules.—89. Their number variable.—90. Analysis of the milk of different animals.—91. Richness of woman's milk.—92. Analogy of milk to blood.—93. Import- ance of the quality of milk.—94. Its richness ascertained.— 95. Quévenne's hydrometer applied to milk.—96. Its fallacy. —97. Donn'e's lactoscope.—98. Objections to it answered.— 99. Frauds practised by milk vendors.—100. Fore-milk and after-milk.—101. Self-engraved photographic pictures.	97

THE LOCOMOTIVE.

CHAP. I.—1. Familiar to every eye.—2. Its mechanism not generally understood.—3. Object of this Treatise.—4. Two modes of pro- pelling wheel carriages.—5. How locomotive is propelled.— 6. Action of piston-rod on wheels.—7. Dead points.—8. Un- equal action.—9. How remedied.—10. Connection of piston- rods with wheels.—11. Wheels fixed on their axles.—12. Form of locomotive.—13. Driving-wheels.—14. Coupled wheels.— 15. Consumption of steam.—16. Evaporating power of boiler determines efficacy of engine.—17. Fire-box.—18. Tubes through boiler.—19. Fuel.—20. Blast-pipe.—21. Tender.—22. Plans and sections, with their description	113
---	-----

CHAP. II.—23. Speed.—24. Locomotive stock.—25. What record of the performance and condition of an engine should be kept.— 26. Cause of renewals of English locomotives.—27. Average mileage of engines.—28. Locomotive requires rest.—29. Expense of cleaning and lighting.—30. Reserve engines.—31. Bank engines.—32. Time they are kept standing.—33. Economy of fuel.—34. Register of consumption.—35. Small amount of useful service obtained.—36. On Belgian lines.—37. On other Con- tinental lines.—38. On London and North Western line.— 39. Comparisons between lines not fairly instituted.—40. Legi- timate test of comparison.—41. Amount of locomotive stock required.—42. Gross receipts of European Railways in 1850.— 43. Mileage of the same.—44. Great increase since.—45. Enormous consumption of coal.—46. Mileage of passengers and goods	129
---	-----

THE THERMOMETER.	PAGE
1. Heat.—2. Sensible heat.—3. Latent heat.—4. Contraction and dilatation.—5. Liquefaction and solidification.—6. Vaporisation and condensation.—7. Incandescence.—8. Combustion.—9. Temperature.—10. Conduction.—11. Radiation.—12. Some bodies are pervious to heat.—13. Some reflect heat.—14. Means of measuring the degrees of heat.—15. Mercurial thermometer.—16. Preparation of mercury.—17. Selection of tube.—18. Formation of bulb.—19. How the tube is filled.—20. Scale applied.—21. Graduation of scale.—22. Zero point.—23. Standard points.—24. Freezing and boiling temperatures universally adopted.—25. Fahrenheit's scale.—26. Centigrade.—27. Reaumur's.—28. Increase of volume of mercury.—29. Uniformity of its dilatation.—30. Standard thermometer.—31. Range of scale.—32. Why mercury is employed in thermometers.—33. Self-registering thermometers.—34. Alcohol thermometers.—35. Air thermometer.—36. Differential thermometer	145

THE NEW PLANETS.

1. Discovery of these planets.—2. The old planets.—3. Numerical law of their distances.—4. A missing planet.—5. Conjecture of Professor Bode.—6. Discovery of Ceres.—7. Of Pallas.—8. Theory of Dr. Olbers—a broken planet.—9. Discovery of Juno.—10. Of Vesta.—11. Rapid discovery of the others.—12. Table of the group.—13. Circumstances corroborating the theory of Dr. Olbers.—14. Amateur astronomers.—15. Minute bulk of these planets.—16. Corroboratory of Dr. Olbers' theory.—17. Force of gravity upon them	161
---	-----

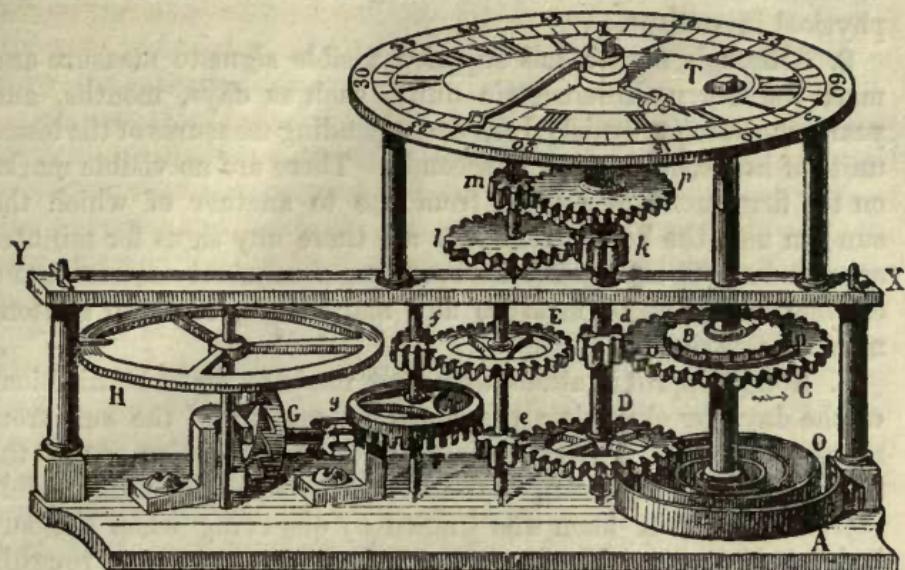
LE VERRIER AND ADAMS' PLANET.

1. Surprise excited by the discovery.—2. How a body may be discovered without seeing it.—3. Generalisation of the principle.—4. Its application to the case of Neptune.—5. Condition of the solar system before the discovery.—6. Observed disturbances of Uranus.—7. Great regularity of these effects.—8. How they would be produced by a more distant planet.—9. Calculations of Le Verrier and Adams.—10. Elements of the sought planet according to these geometers.—11. Its actual discovery.—12. Its corrected elements.—13. Discrepancies between the actual and predicted elements explained.—14. Comparison of the effects of the real and predicted planets.—15. The discovery not to be ascribed to chance.—16. The period of Neptune computed.—17. Computation of his distance.—18. Its prodigious orbital motion.—19. Illustrated by a railway train.—20. Its magnitude.—21. Its satellite.—22. Its weight.—23. Its bulk.—24. The sun's light and heat upon it.—25. The sun's apparent diameter seen from it.—26. Its suspected ring	171
--	-----

MAGNITUDE AND MINUTENESS.

	PAGE
1. Relative magnitude.—2. Manifestations of Divine wisdom.— 3. Smallness of great mountains compared with the bulk of the earth.—4. Of the earth compared with Jupiter and Saturn.— 5. With the Sun.—6. With other celestial objects.—7. Minute particles of which all bodies are composed.—8. Solid, liquid, and gaseous states—how produced.—9. Mechanical subdivision.—10. Pulverised marble.—11. Inequalities of polished surfaces.—12. Particles of gold on touchstone.—13. Filaments of glass.—14. Micrometer wires.—15. Gold leaf.—16. Gilt silver threads for embroidery.—17. Soap bubbles.—18. Insects' wings.—19. Filaments of wool, silk, and fur.—20. Red Particles in the blood.—21. Animalcules.—22. Spider's web.—23. Minute subdivision of a grain of salt.—24. Of sulphate of copper.—25. Of musk.—26. Of strychnine.—27. Of ammoniacal hypo-sulphite.—28. Of sugar.—29. Is matter infinitely divisible?—30. Crystallisation of salt.—31. Ultimate atoms.—32. Natural crystals.—33. Plane of cleavage.—34. Determinate figure of ultimate atoms.—35. Principles of mechanical science independent of this hypothesis.—36. Matter not destructible.—37. By combustion.—38. By evaporation.—39. By destructive distillation.—40. Nor by any other process	193

Fig. 17.



COMMON THINGS.

CLOCKS AND WATCHES.

CHAPTER I.

1. General want of time measurers.—2. No natural measures for short intervals.—3. Approximative expedient by shadows.—4. Sun-dials.—5. Differently constructed for different places.—6. Earliest sun-dials.—7. Clepsydra, or water-clock.—8. Hour-glass.—9. Mercurial time-gauge.—10. Clocks—their chief parts.—11. Regulating power of the pendulum.—12. Uniform rate of vibration.—13. Analysis of a vibration.—14. Experimental verification of isochronism.—15. Moving power sustains the vibration.—16. Vibration not dependent on weight of pendulum.—17. Time of vibration varies with the length.—18. Analysis of motion of pendulous mass.—19. How the pendulum governs the hands.—20. Produces intermitting motion.—21. Pendulum's motion maintained by moving power.

1. AFTER the supply of the absolute necessities of physical existence—food, clothing, and lodging—one of the first wants of a society, emerging from barbarism, is the means of measuring and registering time. In civilised society, all contracts for labour, and for all kinds of service, are based upon time. Even in the cases of the highest public functionaries, and where the service rendered is purely social and intellectual, still it is regulated, limited, and compensated with relation to time. Time measurers

COMMON THINGS—CLOCKS AND WATCHES.

or chronometers were therefore among the earliest mechanical and physical inventions.

2. Although nature has supplied visible signs to measure and mark the larger chronometric units, such as days, months, and years, she has not furnished any corresponding measures of the lesser units of hours, minutes, and seconds. There are no visible marks on the firmament by passing from one to another of which the sun can note the hours, still less are there any signs for minutes or seconds. These subdivisions are therefore merely artificial and conventional, and to measure and mark them, artificial motions must be contrived.

3. Rough approximations were first made to the chief divisions of the day, by observing the apparent motion of the sun from rising to setting. Thus the direction of the meridian, or of the south, being once known, and marked by some fixed and visible object, the time of noon was known by observing when the sun had this direction. The hours before and after noon were roughly estimated by the position of the sun between noon and the times of its rising and setting. Greater precision was given to this method, by erecting a wand or gnomon, the shadow of which would fall upon a level surface, in a direction always opposite to that of the sun. Thus, after sunrise, the shadow would be inclined towards the west, the sun being then towards the east. From the moment of sunrise until noon, the shadow would move continually nearer and nearer to the direction of the north, and at noon it would have exactly that direction. From noon to sunset the shadow would be more and more inclined towards the east.

It is evident, however, that such a dial would not afford uniform indications at all seasons of the year, so that the hour-lines of the shadow determined in spring, for example, would not show the same hours in winter as in summer. Without much astronomical knowledge, it is easy to be convinced of this. At the equinoxes, the sun rises and sets at six o'clock, and at the east and west points precisely; and, therefore, at these seasons, the six o'clock hour-lines of such a dial would be for the morning due west, and for the evening due east. But on the first day of summer (21st June), the sun rises and sets at points of the horizon very much north of the east and west points, and at six o'clock in the forenoon and afternoon its bearing is north of the east and west points.

4. A dial so constructed at any given place would be useless as a time indicator. To render it useful, it would be necessary that the shadow of the style should fall in the same directions at the same hours at all seasons of the year. Now, to attain this object, the style must be not vertical, but must be directed to the celestial pole. It is easy to comprehend that in that case a plane

SUN-DIALS.

passing through the style and the sun would always be carried round the style with an uniform motion by the diurnal motion of the sun, and that at all seasons this plane would at the same hours have the same position.

It is for this reason that the gnomon of sun-dials is placed at such an inclination with the plate of the dial, that when the dial is properly set the gnomon will be directed to the north pole of the heavens, and being so placed, its shadow will fall upon the same lines of the dial at the same hours, whatever be the season of the year.

5. It is evident, therefore, that dials must be differently constructed for places which have different latitudes. We have shown in a former Tract* that the elevation of the celestial pole is equal to the latitude of the place, and consequently the inclination of the gnomon of a sun-dial must be also equal to the latitude of the place where the dial is intended to be set. It follows, therefore, that a dial constructed for London would not be suitable for York, Newcastle, or Edinburgh.

The position of the plate of the dial upon which the shadow of the gnomon is projected is quite unimportant. All that is really important is the direction of the gnomon, which must always be that of the celestial pole, whatever be the position of the plate of the dial. Thus the plate of the dial may be either horizontal, vertical, or oblique. Its position will depend upon the place where it is to be erected. If it be in an open space, as in a garden or field, having a clear exposure on all sides, it will be generally most convenient to make it horizontal; and, hence, in such cases, it is usual to fix it upon the top of a column of three or four feet high, so that it may be easily observed by a person of ordinary height standing near it. Sometimes it is convenient to place it upon the wall of a building, such as a church. A wall with a southern exposure is in that case the most convenient; but to indicate the hours of the early morning in the spring and summer, an eastern exposure would be required, and to indicate those of the late evening a western exposure would be necessary.

Where these vertical dials are erected, it is therefore frequently the practice to establish them at the same time on different walls of the same building.

Whatever be the position of the plate of the dial, the position of the hour-lines upon it is a matter of mere technical calculation, for which the formulæ and principles of spherical trigonometry are necessary, but which is not attended with any difficulty.

* Vol. i. page 102.

It must, however, be observed, that generally the hour-lines are inclined to each other at unequal angles, as may be seen by inspecting any ordinary sun-dial. There is one, and one only, position which could be assigned to the plate of the dial, such that the hour-lines would make equal angles with each other. That position would be at right angles to the gnomon, and a dial so constructed would be suitable to any place, whatever be its latitude. All that would be necessary would be to set it so that the gnomon would be directed to the celestial pole. The sun, however, would shine upon the upper or north side of it during the spring and summer, and on the lower or south side during the autumn and winter. It would, therefore, be necessary that it should be marked on both sides with hour-lines, and that a gnomon should be fixed on both sides.

6. The name dial is derived from the Latin word *dies*, a day, and the invention and use of the instrument as a time indicator is very ancient. According to Herodotus, the invention came to Greece from Chaldæa. The first dial recorded in history is the hemisphere of Berossus, who is supposed to have lived 540 B.C.

7. The first attempts to measure time by motions artificially produced, consisted in arrangements, by which a fluid was let fall in a continuous stream through a small aperture in the pipe of a funnel, the time being measured by the quantity of the fluid discharged. The CLEPSYDRA, or water-clock, of the ancients, was constructed upon this principle. This and the sun-dial were the only instruments contrived or used by the ancients for the measurement of time.

Clepsydras were contrived by the Egyptians, and were in common use under the reign of the Ptolemys. In Rome, sun-dials were used in summer and clepsydras in winter. These instruments, though subject to very obvious defects, were, nevertheless, when skilfully used, susceptible of considerable accuracy, as may be easily conceived, when it is stated, that before the invention of clocks and watches, they were the only chronometric instruments used by astronomers. The chief sources of their irregularities were the unequal celerity with which the fluid is discharged, owing to its varying depth in the funnel and its change of temperature.

8. The common hour-glass comes under this class of chronometric instruments, but is the most imperfect of them. Nevertheless, for certain purposes, it is even now, advanced as we are in the application of science to the arts, still found the most convenient chronometer. The process of ascertaining a ship's rate of sailing or steaming by means of the log affords an example of its use. One man holds the reel from which the line runs off, while another holds the

CLEPSYDRA—SAND-GLASS.

sand-glass, and gives the signal when the sand has run out. The number of knots run off from the reel is then the number of miles per hour in the rate of the vessel. The intervals between the knots, the quantity of sand in the glass, and the aperture through which it falls, are so adapted to each other as to give this result.

9. Notwithstanding the great perfection to which the art of constructing chronometers has attained, an apparatus was not long since proposed by the late Captain Kater for the measurement of very small intervals of time, fractions of a second, for example, which is a modification of the clepsydra. A quantity of pure and clean mercury is poured into a funnel with a small aperture at its apex, so that a stream of the quicksilver shall fall through it. The flow is rendered uniform, by keeping the mercury in the funnel at a constant level. The apparatus is intended in scientific researches to note the exact duration of phenomena, and it is so managed, that the stream issuing from the funnel, is turned over a small receiver at the instant the phenomenon to be observed commences, and is turned away from it the instant the phenomenon ceases. The mercury discharged into the receiver is then accurately weighed, and the number of grains, and parts of a grain it contains, being divided by the number of grains which would be discharged in a second, the number of seconds, and the parts of a second, which elapsed during the continuance of the phenomenon is found.

10. For the purposes of civil life, as well as for the more precise objects of scientific research, all these contrivances have been superseded by clocks and watches, which are now so universal as to constitute a necessary article of furniture in the most humble dwellings, and a necessary appendage of the person in all civilised countries.

All varieties of this most useful mechanical contrivance include five essential parts.

1. A moving power.
2. An indicator, by whose uniform motion time is measured.
3. An accurately divided scale, upon which the indicator moves and by which its motion is measured.
4. Mechanism, by which the motion proceeding from the moving power is imparted to the indicator.
5. A regulator, which renders the motion imparted to the indicator uniform, and which fixes its celerity at the required rate.

Thus, for example, in a common clock, the moving power is the weight suspended by cords over a pulley fixed upon the axle of a wheel, to which the weight in descending imparts a motion of rotation. The indicator is the hand. The scale is the dial plate

COMMON THINGS—CLOCKS AND WATCHES.

upon which the hours, minutes, and sometimes the seconds, are marked by equal divisions, over which the point of the hand moves. The mechanism is a train of wheelwork, so constructed that the rate of rotation of the last wheel upon the axle of which the hand is fixed, shall have a certain proportion to the rate of rotation of the first wheel, upon the axle of which the weight is suspended. And if, as is generally the case, there be two or three hands, then the wheel-work is so constructed, that while one of the hands makes one revolution, another shall make twelve revolutions, and the third shall make sixty revolutions during a single revolution of the latter, and therefore seven hundred and twenty during a single revolution of the former.

If no other appendage were provided, the weight would, in such an apparatus, descend with a continually increasing velocity, and would therefore impart to the hands a motion of rotation more and more rapid, which would not consequently serve as a measure of time. This defect is removed by the addition of a pendulum, combined with a wheel upon which it acts called the escapement. It is the property of the pendulum that its oscillations are necessarily made always in equal times, and its connection with the escapement-wheel is such, that one tooth of that wheel, and no more, is allowed to pass the upper part of the pendulum during each oscillation right and left. But this escapement-wheel itself forms part of the train of wheel-work by which the first wheel, moved by the descending weight, is connected with the wheels which move the hands, and consequently, by regulating and rendering uniform the motion of this escapement-wheel, the pendulum necessarily regulates and renders uniform the motion of the entire apparatus.

The instrument thus arranged, therefore, imparts an uniform motion of rotation to each of the hands, but this is not enough to render it a convenient time measurer. It is necessary that the motion of the hands should have some definite and simple relation to the natural and conventional division of time into days, hours, minutes, and seconds. For this purpose it is required not only that the hands should move uniformly, but that the first, or slowest of them, should make two complete revolutions in a day, or a single revolution in twelve hours; and, as a necessary consequence of this, that the second should make a single revolution in an hour, and the third in a minute.

11. From what has been stated, it will be apparent that the actual rate of motion imparted to the hands will be determined by the rate of oscillation of the pendulum. It has been shown that for each oscillation, right and left, of the pendulum, one tooth of the escapement-wheel passes, and if the escapement-wheel have

THE PENDULUM.

thirty teeth, and if the pendulum take one second to make a single swing, it will allow the escapement-wheel to make a complete revolution while it makes thirty swings from right to left, and thirty from left to right, that is, in sixty seconds, or one minute; so that, if the axis of the third hand were in this case fixed upon the axle of the escapement-wheel, that hand would make one complete revolution in a minute, and consequently the second would make one complete revolution in one hour, and the third in twelve hours. The required conditions would therefore be in this case fulfilled.

To render this explanation of the regulating property of the pendulum complete, it will be sufficient to show—1st, that the time of vibration must be always rigorously the same with the same pendulum; 2nd, that this time can be made shorter or longer by varying the length of the pendulum, so that a pendulum can always be constructed which will vibrate in one second, or in half a second, or, in short, in any desired time; and 3rd, that the connection of the pendulum with the escapement-wheel can be so constructed, that the motion of the latter shall be governed by the vibrations of the former, in the manner already described.

A pendulum consists of a heavy mass attached to a rod, the upper extremity of which rests upon a point of support in such a manner as to have as little friction as possible. Such an instrument will remain at rest when its centre of gravity is in the vertical line immediately under the point of suspension or support. But if the centre of gravity be drawn from this position on either side, and then disengaged, the instrument will swing horizontally from the one side to the other of the position in which it would remain at rest, the centre of gravity describing alternately a circular arc on the one side or the other of its position of rest. If there were neither friction nor atmospheric resistance, this motion of vibration or oscillation on either side of the position of equilibrium would continue for ever; but in consequence of the combined effects of these resistances, the distances to which the pendulum swings on the one side and on the other are continually diminished, until, after the lapse of an interval, more or less protracted, it comes to rest.

12. It is related that Galileo, when a youth, happening to walk through the aisles of a church in Pisa, observed a chandelier suspended from the roof, whose position had been accidentally disturbed, and which was consequently in a state of oscillation. The young philosopher, contemplating the motion, was struck with the fact, that although the range of its vibration was continually diminished as it approached a state of rest, the times of the vibration were sensibly equal, the motion becoming slower

as the range of the oscillations became more limited. This led him to infer that property of the pendulum expressed by the word isochronism, in virtue of which the vibrations, whether in longer or shorter arcs, are performed in the same time.

Although, however, as we shall presently show, pendulums possess this property when the arcs of vibration are very small, they do not continue to manifest it when the range of vibration becomes more considerable.

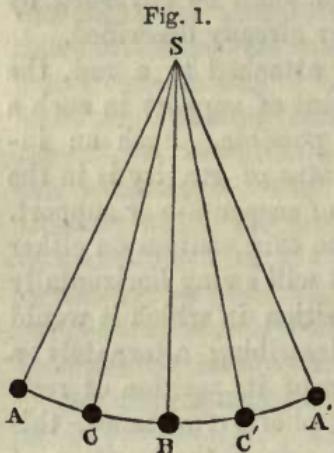
13. To simplify the exposition of the important theory of the pendulum, it will be convenient, in the first instance, to consider it as composed of a heavy mass of small magnitude, suspended by a wire or a string, the weight of which may be neglected. Thus, let us suppose a small ball of lead suspended by a fine silken string, the length of which is incomparably greater than the diameter of the leaden ball. Such an arrangement is called the *simple pendulum*.

Let s , fig. 1, be the point of suspension; let $s\ b$ be the fine silken thread by which the ball b is suspended, and the

weight of which, in the present case, is neglected. Let b be the position of the ball when in the vertical under the point of suspension s . In that position the ball would remain at rest; but if we suppose the ball drawn aside to the position A , it will, if disengaged, fall down the arc $A\ B$, of which the centre is s , and the radius the length of the string. Arriving at B , it will have acquired a certain velocity, which, in virtue of its inertia, it will have a tendency to retain, and with this velocity it will commence to move through the arc $B\ A'$. Supposing neither the

resistance of the atmosphere nor friction to act, the ball will rise through an arc $B\ A'$ equal to $B\ A$; but it will lose the velocity which it had acquired at B ; for it is evident that it will take the same space, and the same time, to destroy the velocity which has been acquired, as to produce it. Thus, the velocity at B , being acquired in falling through the arc $A\ B$, will be destroyed in rising through the equal arc $B\ A'$.

Having arrived at A' , the ball, being brought to rest, will again fall from A' to B , and at B will have again acquired the same velocity which it had obtained in falling from A to B , but in the contrary direction; and in the same manner it may be explained that this velocity will carry it from B to A . Having



ISOCHRONISM.

arrived at A, the ball, being again brought to rest, will fall once more from A to B, and so the motion will be continued alternately between A and A'.

The motion of the pendulum from A to A', or from A' to A, is called an *oscillation*, and its motion between either of those points and B is called a semi-oscillation, the motion from B to A or from B to A' being called the ascending semi-oscillation, and the motion from A or A' to B, the descending semi-oscillation.

The time which elapses during the motion of the ball between A and A' is called the *time of one oscillation*.

It is evident, from what has been stated, that the time of moving from either of the extremities A, A', of the arc of oscillation to the point B, is half the time of an oscillation.

If, instead of falling from the point A, the ball had fallen from the point c, intermediate between A and B, it would have then oscillated between c and c'; two points equally distant from B, and the arc of oscillation would have been c c', more limited than A A'.

But in commencing its motion from c, the declivity of the arc down which it falls towards B would be evidently less than the declivity at A; consequently the force which would accelerate it, commencing its motion at c, would be less than that which would accelerate it, commencing its motion at A. The ball, therefore, commencing its motion at A, would be more rapidly accelerated than when it commences its motion at c.

The result of this is, that, although the arc A B may be twice as long as the arc c B, the *time* which the ball takes to fall from A to B will not be sensibly different from the time it takes to fall from c to B, provided that the arc of oscillation A B A' is not considerable.

It was at first supposed, as we have just stated, that, whether the oscillations were longer or shorter, the times would be absolutely the same. Accurately speaking, however, this is not the case: but if the total extent of the oscillation A A' do not exceed 5° or 6° , then the time of oscillation in it may be considered, practically, the same as in the lesser arcs.

14. This important principle may be easily experimentally verified. Let two small leaden balls be suspended from the same point of support, but one being in advance of the other, so that in oscillating the two balls shall not strike each other. This being done, let one of the balls be drawn from its point of rest through an angle less than 3° , and let it be disengaged. It will oscillate as described above. Let the other ball be now drawn from its point of rest through a much less angle, and let it be so

disengaged that it shall commence its oscillation at the same moment with the commencement of one of the oscillations of the other ball.

Let it, in short, be so managed, that when the one ball is at A, the other shall be at c; and that both shall commence their descending motion towards B at the same moment. It will be then found that their oscillations will be synchronous for a considerable length of time, that is to say, the balls will arrive at A' and c', respectively, at the same instant; and returning, will simultaneously arrive at A and c respectively.

If, in this case, the oscillation of the ball A were made through an arc, even as great as 10° , that is to say, 5° each side of the vertical, the oscillation of the ball c being made through an arc of 2° , it would be found that 10001 oscillations of the latter would be equal to 10000 oscillations of the former, so that the actual difference between their times of oscillation would not exceed the ten thousandth part of such time.

15. In the practical application of the pendulum, however, this departure from absolute isochronism, small as it is, becomes unimportant; for a power is always provided, by which the loss of motion which would be produced by friction and atmospheric resistance is repaired, and the magnitude of the oscillations is maintained uniform, as we shall presently show.

16. It might be expected that the time of oscillation of different pendulums would depend, more or less, upon the weight of the matter composing them, and that a heavy body would oscillate more rapidly than a lighter one. Both theory and experience, however, prove the result to be otherwise. The force of gravity which causes the pendulum to oscillate acts separately on all the particles composing its mass; and if the mass be doubled, the effect of this force upon it is also doubled; and, in short, in whatever proportion the mass of the pendulum be increased or diminished, the action of the force of gravity upon it will be increased or diminished in exactly the same proportion, and consequently the velocity imparted by gravity to the pendulous mass at each instant will be the same.

It is easy to verify this by experiment. Let different balls of small magnitude, of metal, ivory, and other materials, be suspended by light silken strings of the same length, and made to oscillate; their oscillations will be found to be equal.

17. If pendulums of different lengths have similar arcs of oscillation, the times of oscillation of those which are shorter will be less than the times of oscillation of those which are longer. Let a, b, c, d, and e, fig. 2, be five small leaden balls, suspended by light silken strings to the point of suspension s, and let all

RATE OF PENDULUM.

of them be supposed to form pendulums, having the same angle of oscillation. The arc of oscillation of the ball a will be $a\ a''''$, that of b will be $b\ b''''$, that of c , $c\ c''''$, and so on. In commencing to fall from the points a , b , c , d , e towards the vertical line, these five balls are equally accelerated, inasmuch as the circular arcs down which they fall are all equally inclined at this point to the vertical line. The same will be true if we take them at any corresponding points, such as a', b', c', d', e' . It may therefore be concluded, that throughout the entire range of oscillation of each of these five pendulums, they will be impelled by equal accelerating forces.

Now it is shown by the principles of mechanics, that when bodies are impelled by the same or equal accelerating forces, the spaces through which they move are proportional to the squares of the times of their motion; therefore it follows, that the lengths of these arcs of oscillation are proportional to the squares of the times. But the lengths of these arcs are evidently in the same proportion as the lengths of the pendulums, that is to say, the arc $a\ a''''$ is to $b\ b''''$ as $s\ a$ is to $s\ b$, and the arc $b\ b''''$ is to $c\ c''''$ as $s\ b$ is to $s\ c$, and so on.

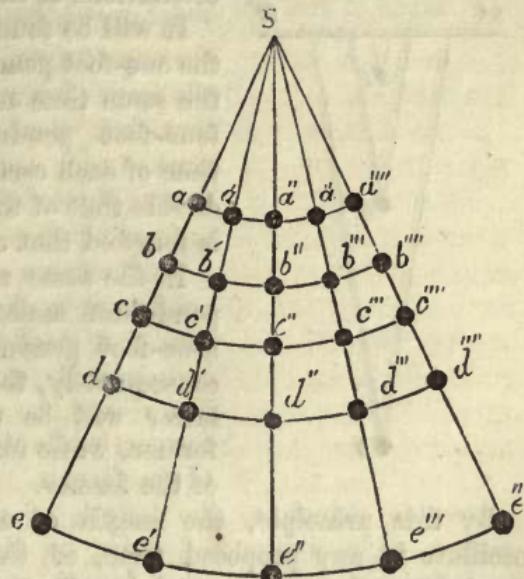
It follows, therefore, that the squares of the times of oscillation of pendulums are as their lengths, or, what is the same, the times of oscillation are as the square roots of their lengths. This principle is easily verified experimentally.

Let three small leaden balls be suspended vertically under each other by means of loops of silken thread, as represented in fig. 3, and in such a manner that they can all oscillate in the same plane at right angles to the plane of the diagram, the suspending loops not interfering with each other.

Let the loops be so adjusted that the distance of the ball 1 below the line $M\ N$ shall be 1 foot, the distance of the ball 4, 4 feet, and the distance of the ball 9, 9 feet.

Let the ball 9 be put in a state of oscillation through small arcs, and let the ball 4 be then drawn from its vertical position,

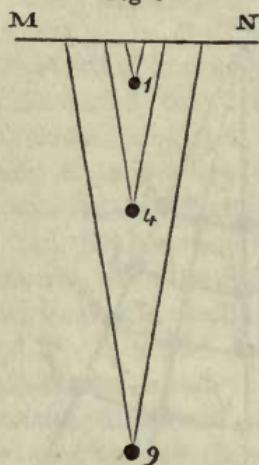
Fig. 2.



COMMON THINGS—CLOCKS AND WATCHES.

and disengaged so as to commence one of its oscillations with an oscillation of the ball 9; and in the same manner let the ball 1 be started simultaneously with one of the oscillations of the ball 9.

Fig 3



It will be found that two oscillations of the one-foot pendulum are made in exactly the same time as a single oscillation of the four-foot pendulum; consequently, the time of each oscillation of the latter will be double that of the former, while its length is fourfold that of the former.

In the same manner, while the one-foot pendulum makes three oscillations, the nine-foot pendulum will make one, and, consequently, the time of oscillation of the latter will be three times that of the former, while its length is nine times that of the former.

By this principle, the length of a pendulum which would oscillate in any proposed time, or the time of oscillation of a pendulum of any proposed length can be ascertained, provided we know the length of a pendulum which oscillates in any given time.

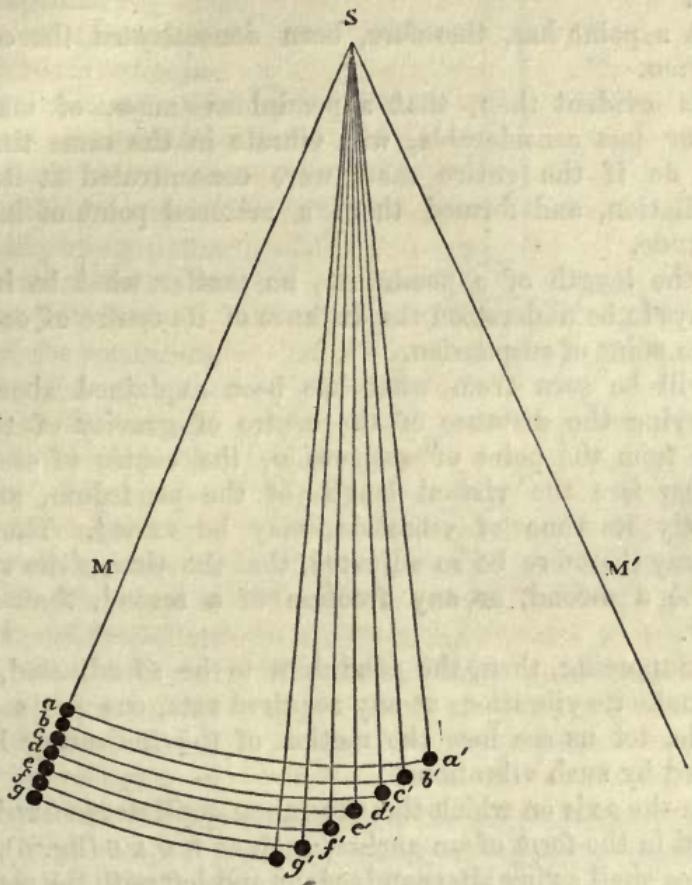
18. We have hitherto supposed that the pendulous body is a heavy mass of indefinitely small magnitude, suspended by a wire or string having no weight. These are conditions which cannot be fulfilled in practice. Every real pendulous body has a definite magnitude, its component parts being at different distances from the point of suspension; the rod which sustains it is of considerable weight, and all the points of this rod, as well as those of the pendulous mass itself, are at different distances from the point of suspension. In estimating, therefore, the effect of pendulums, it is necessary to take into account this circumstance.

Let us suppose a, b, c, d, e, f, g (fig. 4), to be as many small heavy balls connected by independent strings, the weight of which may be neglected, with a point of suspension s , and let these seven balls be supposed to vibrate between the positions $s M$ and $s M'$. Now if these balls were totally independent of each other, and connected with the point of suspension by independent strings, they would all vibrate in different times, those which are nearer the point s vibrating more rapidly than those which are more distant from it. If, therefore, they be all disengaged at the same moment from the line $s M$, those which are nearest to s will get the start of those which are more distant, and at any intermediate position between the extremes of their

CENTRE OF OSCILLATION.

vibration they will assume the positions a' , b' , c' , d' , e' , f' , g' . That which is nearest to the point S , and which is the shortest pendulum, will be foremost, since it has the most rapid vibration. The next in length, b' , will follow it, and so on ; the most remote from S being the longest pendulum, g' being the last in order.

Fig. 4.



Now if, instead of supposing these seven balls to be suspended by independent strings, we imagine them to be fixed upon the same wire, so as to be rendered incapable of having any independent motion, and compelled to keep in the same straight line ; then it is evident, that while the whole series vibrates with a common motion, those which are nearest to the point of suspension will have a tendency to accelerate the motion of those which are more distant, while those which are more distant will have a tendency to retard the motion of those which are nearer.

These effects will produce a mutual compensation ; b and c will vibrate slower than they would if they were moving freely, while e and f will evidently move more rapidly than if they were moving

freely. Among the series, there will be found a certain point, which will separate those which are moving slower than their natural rate, from those which are moving faster than their natural rate; and a ball placed at this point would vibrate exactly as it would do if no other balls were placed either above or below it. Such a ball would, as it were, be the centre which would divide those which are accelerated from those which are retarded.

Such a point has, therefore, been denominated the *centre of oscillation*.

It is evident then, that a pendulous mass, of magnitude more or less considerable, will vibrate in the same time as it would do if the entire mass were concentrated at its centre of oscillation, and formed there a material point of insensible magnitude.

By the length of a pendulum, no matter what be its form, is always to be understood the distance of its centre of oscillation from its point of suspension.

It will be seen from what has been explained above, that by varying the distance of the centre of gravity of the pendulum from the point of suspension, the centre of oscillation, and therefore the virtual length of the pendulum, and consequently its time of vibration, may be varied. The instrument may therefore be so adjusted, that the time of its vibration shall be a second, or any fraction of a second, that may be desired.

19. Supposing, then, the pendulum to be so adjusted, that it shall make its vibrations at any required rate, one per second for example, let us see how the motion of the indicating hands is governed by such vibrations.

Upon the axis on which the pendulum oscillates is fixed a piece of metal in the form of an anchor, such as D B A C (fig. 5), so that this piece shall swing alternately right and left with the pendulum. Two short pieces, m and m', called pallets, project inwards at right angles to it from its extremities A and c.

The form and dimensions of the anchor A B C are accommodated to those of the escapement-wheel, w w', which is part of the clockwork, and which, in common with the other wheels forming the train, is moved in the direction indicated by the arrow by the weight or main-spring. When the anchor swings to the right the pallet m enters between two teeth of the wheel, the lower of which coming against it, the motion of the wheel is for the moment arrested. When it swings to the left, the pallet m is withdrawn from between the teeth, and the wheel is allowed to move, but only for a moment, for the other pallet m' enters

ESCAPEMENT.

between two teeth at the other side, the upper of which coming against it the motion of the wheel is again arrested.

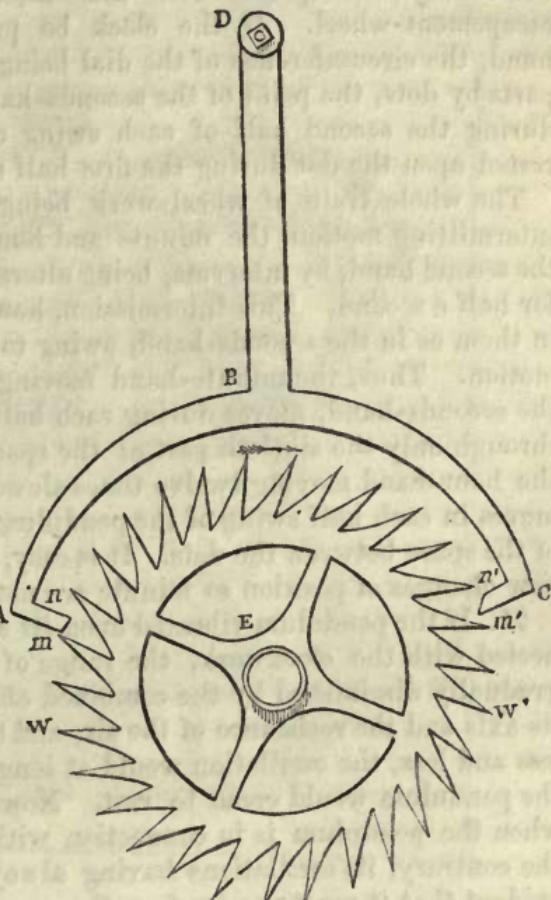
The wheel, therefore, is thus made to revolve on its axis, E, not with a continuous motion, as would be the case if it were impelled by the weight or mainspring, without the interference of any obstacle, but with an intermittent motion. It moves by starts, being stopped alternately by one pallet or the other coming in the way of its teeth.

When the pendulum, and therefore the anchor, is at the extreme right of its play, the pallet, m, having entered between two teeth, a tooth rests against its lower side, the wheel is arrested, and the pallet, m', is quite disengaged from, and clear of, the teeth of the wheel. When in swinging to the left the arm D B becomes vertical, the tooth of the wheel on the left has just *escaped* from the pallet, m, and the wheel being liberated, has just commenced to be moved by the force of the weight or mainspring. But at the same moment the pallet, m', enters between the teeth of the wheel on the right, and when the anchor has arrived at the extreme left of its play, the tooth of the wheel, which is above the pallet, m', will have fallen upon it, so that the motion will again be arrested.

Thus it appears, that during the first half of the swing from right to left, the motion of the wheel is arrested by the pallet, m, and during the remaining half of the swing the wheel moves, but is arrested the moment the swing is completed.

In like manner it may be shown, that during the first half of the swing from left to right, the motion of the wheel is arrested by the pallet, m', that it is liberated and moves during

Fig. 5.



the latter half swing, and is again arrested when the swing is completed.

20. The motion which is imparted to the hands upon the dial necessarily corresponds with this intermitting motion of the escapement-wheel. If the clock be provided with a seconds-hand, the circumference of the dial being divided into sixty equal parts by dots, the point of the seconds-hand moves from dot to dot during the second half of each swing of the pendulum, having rested upon the dot during the first half swing.

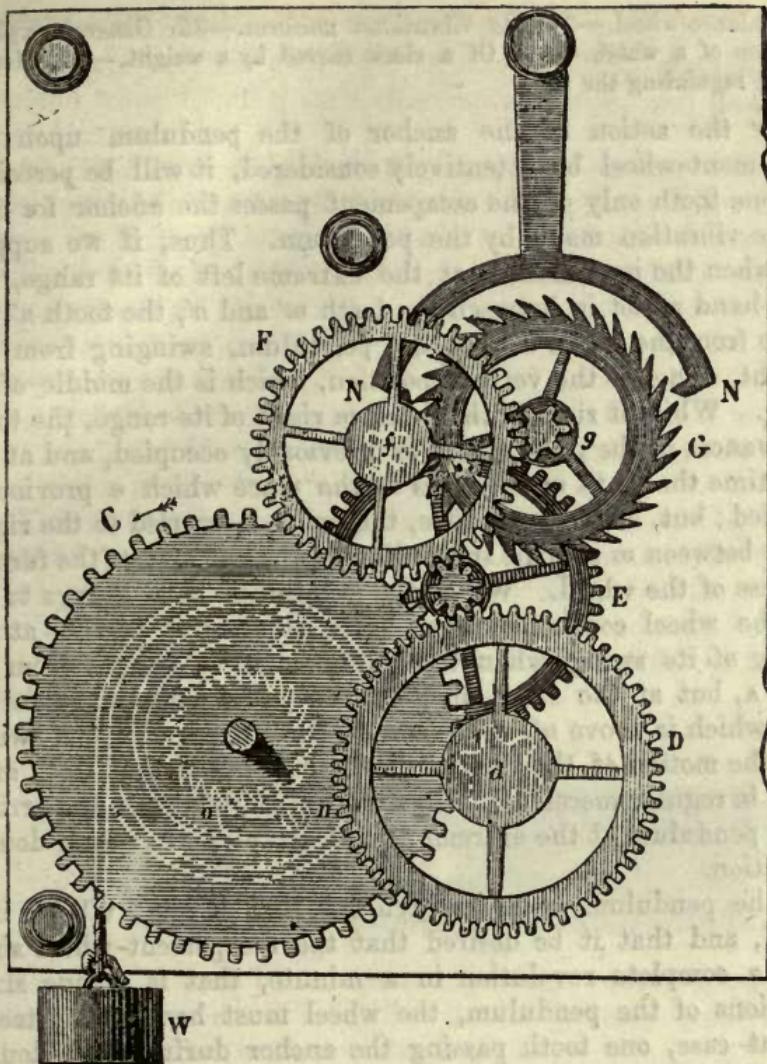
The whole train of wheel-work being affected with the same intermitting motion, the minute and hour hands must move, like the second hand, by intervals, being alternately moved and stopped for half a second. This intermission, however, is not so observable in them as in the seconds-hand, owing to their comparatively slow motion. Thus, the minute-hand moving sixty times slower than the seconds-hand, moves during each half swing of the pendulum through only the sixtieth part of the space between the dots, and the hour-hand moving twelve times slower than the minute-hand moves in each half swing of the pendulum, through the 360th part of the space between the dots. It is easy, therefore, to comprehend how changes of position so minute are not perceptible.

21. If the pendulum vibrated upon its axis of suspension unconnected with the clockwork, the range of its oscillation would be gradually diminished by the combined effects of the friction upon its axis and the resistance of the air, and this range thus becoming less and less, the oscillation would at length cease altogether, and the pendulum would come to rest. Now this not being the case when the pendulum is in connection with the wheelwork, but on the contrary, its oscillations having always the same range, it is evident that it must receive from the escapement-wheel some force of lateral impulsion, by which the loss of force caused by friction and the resistance of the air is repaired.

It is easy to show how the effect is produced. It has been shown that during the first half of each swing, a tooth of the escapement-wheel rests upon one or other pallet of the anchor. The pallet re-acts upon it with a certain force, arresting the motion of the wheelwork, and receives from it a corresponding pressure. This pressure has a tendency to accelerate the motion of the pendulum, and this continues until the tooth slips off, and is liberated from the pallet. It is this force which repairs the loss of motion sustained by the pendulum by friction and atmospheric resistance.

Thus we see, that while on the one hand the pendulum regulates and equalises the motion imparted to the wheelwork by the weight or mainspring, its own range is equalised by the reaction of the weight or mainspring upon it.

Fig. 18.



COMMON THINGS.

CLOCKS AND WATCHES.

CHAPTER II.

22. Action of pendulum on escapement wheel.—23. Rate of motion of hands produced by tooth and pinion work.—24. Method of making pinions.—25. Mutual action of toothed wheels.—26. Wheel and pinion.—27. Bevelled and crown wheels.—28. Weight applied as a moving power.—29. Why hands not turned back when clock is wound up.—30. Mainspring.—31. Its power variable.—32. The fusee.—33.

COMMON THINGS—CLOCKS AND WATCHES.

Balance-wheel.—34. Its vibrations uniform.—35. General explanation of a watch.—36. Of a clock moved by a weight.—37. Method of regulating the rate.

22. IF the action of the anchor of the pendulum upon the escapement-wheel be attentively considered, it will be perceived that one tooth only of the escapement passes the anchor for each double vibration made by the pendulum. Thus, if we suppose that when the pendulum is at the extreme left of its range, the right-hand pallet is between the teeth m' and n' , the tooth n' will escape from the pallet c when the pendulum, swinging from left to right, comes to the vertical position, which is the middle of its swing. While it rises to the extreme right of its range, the tooth n' advances to the place which m' previously occupied, and at the same time the tooth m advances to the place which n previously occupied; but, at the same time, the pallet A, carried to the right, enters between m and the succeeding tooth, and arrests the further progress of the wheel. When the pendulum then swings to the left, the wheel continues to be arrested until it arrives at the middle of its swing, when the tooth below m escapes from the pallet A, but at the same moment the pallet c enters below the tooth which is above n' , and receiving it at the end of the swing, stops the motion of the wheel. Thus it appears, that tooth after tooth, in regular succession, falls upon the pallet c upon the arrival of the pendulum at the extreme left of its play after each double oscillation.

If the pendulum be so constructed that it shall vibrate in a second, and that it be desired that the escapement-wheel shall make a complete revolution in a minute, that is during sixty vibrations of the pendulum, the wheel must have thirty teeth. In that case, one tooth passing the anchor during each double oscillation from right to left, and back from left to right, thirty teeth, that is the whole circumference of the wheel, will pass the anchor in thirty double oscillations, or in sixty single swings of the pendulum, the time of each swing being one second.

23. The manner in which different rates of revolution can be imparted to the different hands of a clock or watch, by tooth and pinion work, is easily rendered intelligible.

The wheels commonly used in watch and clockwork are formed from thin sheets of metal, usually brass, which are cut into circular plates of suitable magnitude, upon the edges of which the teeth are formed. The edges of the wheels thus serrated are brought together, the teeth of each being inserted between those of the other, so that if one be made to revolve upon its axle, its teeth pressing upon those of the other, will impart a motion of revolution to the other.

WHEELS AND PINIONS.

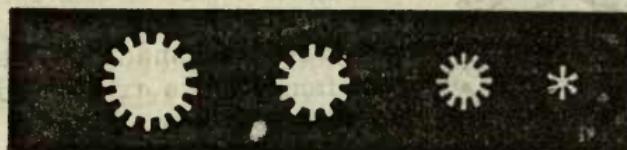
When a large wheel works in the teeth of a much smaller one, which is a very frequent case in all species of wheelwork, the smaller wheel is called for distinction a **PINION**, and its teeth are called **LEAVES**.

24. The method of manufacturing the pinions and smaller wheels used in watch and clockwork is very ingenious. A rod of wire, the diameter of which a little exceeds that of the wheel or pinion to be made, is drawn through an aperture cut in a steel plate, having the exact form and magnitude of the wheel or pinion to be formed. After being forced through this aperture by the ordinary process of wire-drawing, it is converted into a *fluted* wire, the ridges of the fluting corresponding exactly in form and magnitude to the edge of the aperture, and therefore to the teeth or leaves of the pinion or wheel.

This fluted wire, called *pinion wire*, is then cut by a cutter, adapted to the purpose, into thin slices, at right angles to its length. Each slice is a perfect wheel, or pinion; and it is evident that all of them must be absolutely identical in form and magnitude.

Such a wire-drawing plate, with apertures of different forms and sizes, is represented in fig. 6.

Fig. 6.

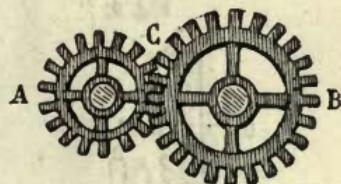


25. Two wheels of unequal magnitude, working one in the other, are represented in fig. 7. It will be easily perceived, that in this case their motions must be in contrary directions. Thus, if the wheel A move in the direction of the hand of a watch, the wheel B must move in the contrary direction.

Also, the rate at which they revolve on their axles will be in the inverse proportion of the number of their teeth. Thus, if the wheel B have fifty teeth, while the wheel A has only ten, it is evident that one revolution of B must be accompanied by five revolutions of A, since an equal number of teeth of each wheel must necessarily pass the point of contact c in the same time.

Now, in clock and watchwork, one of the objects to be attained is to cause certain wheels to revolve in a given numerical proportion to others. Thus, that upon the axis of which the seconds

Fig. 7.



COMMON THINGS—CLOCKS AND WATCHES.

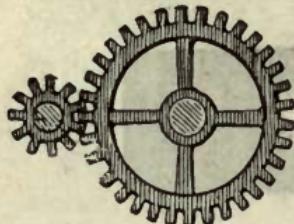
hand is fixed must make sixty revolutions, while that upon which the minute hand is fixed makes one. This would, therefore, be accomplished if the two wheels worked one in the other, the one having ten teeth and the other six hundred. But it is not necessary or convenient that the two wheels should thus be immediately in connection. Two or more wheels or pinions may be interposed between them, so that their relative velocities of rotation may result from the combined relations of the numbers of teeth or leaves in all the intermediate wheels and pinions.

26. A wheel working in a pinion is represented in fig. 8. When a very slow motion of rotation is to be converted into one many times faster, or *vice versa*, this expedient is usually adopted.

A wheel and pinion are often fixed upon the same axis at more or less distance asunder. The pinion in this case may drive or be driven by a smaller wheel at a distance from the first, which is often convenient in clockwork and other machinery.

Thus, in fig. 17, the wheel *c* drives the pinion *d* which is fixed upon the axle of *D*, and drives it. The wheel *D* drives the pinion *e*, which drives the wheel *E* on the same axle, and the wheel *E*

Fig. 8.



drives the pinion *f*, which drives the wheel *F*, and so on. In this way combinations of wheels and pinions may be arranged so as to modify in any desired manner the rate of rotation, and to transfer the rotation from axle to axle according to any proposed conditions.

27. In all these cases the axles round which the motion of rotation is produced are parallel one to another. In many cases, as well in clockwork as in other machinery, it is required to produce a motion of

Fig. 9.

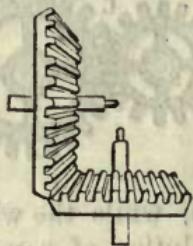
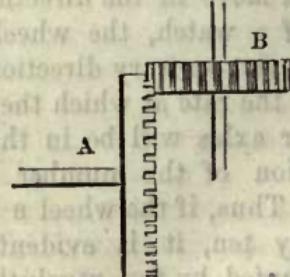


Fig. 10.



rotation round an axis at right angles to that upon which the motion already obtained is produced.

This is very simply and beautifully effected by either of two expedients, one of which is called BEVELLED, and the other CROWN wheels.

CLOCK WEIGHT.

The manner in which the object is attained by bevelled wheels will be evident by inspecting fig. 9. The teeth in this case are formed upon a surface inclined to the axis at an angle of 45° , and the two axles make with each other consequently an angle of 90° .

In the crown wheel A, fig. 10, the teeth are raised upon the edge parallel to the axis, and work in the teeth or leaves of a wheel or pinion B, whose axle is at right angles to that of A.

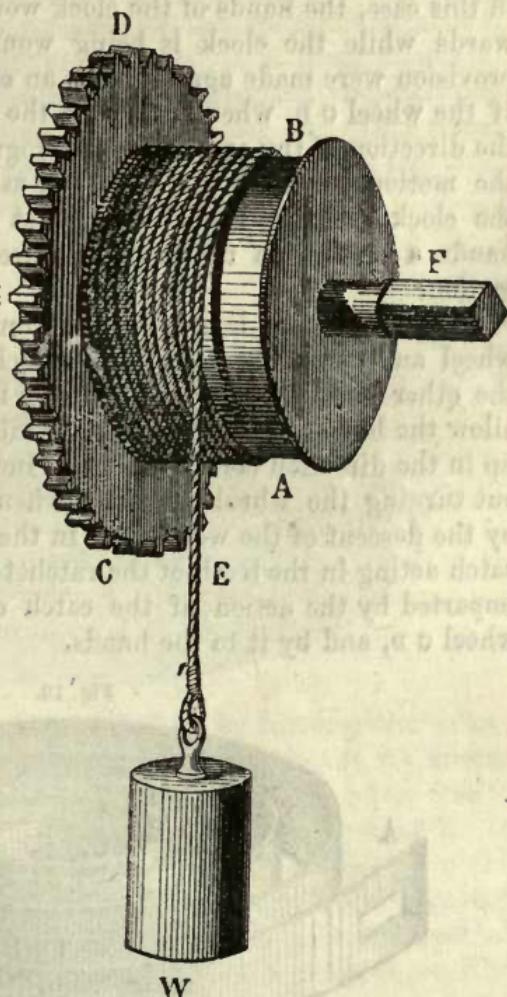
In clockwork, the crown wheel is the expedient used for this purpose, bevelled wheels being generally preferred in larger and heavier applications of wheelwork.

28. It has been already stated that the moving power applied to clock or watchwork is either a weight or a mainspring.

If a weight be the moving power, it is suspended to a cord which is coiled upon a drum fixed upon an horizontal axis, the first wheel of the train which gives motion to the hands being fixed on the same axis, so that it shall turn when the drum turns.

Such an arrangement is represented in fig. 11, where A B is the drum, C D the wheel attached to it and moved by it, w the weight which is the moving power suspended to the cord E, which is coiled upon the drum A B. The end, F, of the axis of the drum projecting beyond it, is made square, so as to receive a key made to fit it, by which it is turned, so as to coil the cord upon the axis, when it has been uncoiled by the descending motion of the weight.

Fig. 11.*



* This, and most of the succeeding diagrams have been copied from the excellent work "Cours Élémentaire de Mécanique," par Charles Delaunay — Victor Masson—Paris, 1854, with the permission of the author and publisher.

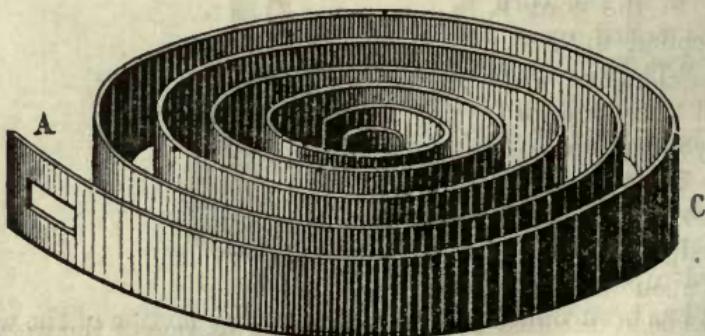
COMMON THINGS—CLOCKS AND WATCHES.

The direction in which the wheel *c d* is turned by the force of the descending weight is indicated by the arrow, and in that direction it will continue to turn so long as the weight acts upon the coil of the cord upon the drum. But so soon as the cord, by the continued descent of the weight, shall have been discharged from the drum, the rotation imparted to *c d* must cease. It is then that the key must be applied to the square end, *f*, of the axis of the drum, and turned continually in the direction contrary to that in which the weight would turn the drum in descending.

29. It will no doubt be perceived by the attentive reader, that, in this case, the hands of the clock would be always turned backwards while the clock is being wound up, unless some special provision were made against such an effect; for it is evident, that if the wheel *c d*, when turned by the descent of the weight *w*, in the direction of the arrow, give a progressive motion to the hands, the motion imparted to *c d*, by the ascent of the weight *w*, while the clock is being wound up, must necessarily impart to the hands a motion in the contrary direction, that is a backward motion.

In all clocks this is prevented by an expedient called a ratchet wheel and catch, the one being attached to the barrel *A B*, and the other to the face of the wheel *c d*, the effect of which is to allow the barrel *A B*, to be turned while the clock is being wound up in the direction contrary to that indicated by the arrow without turning the wheel *c d*; but when the barrel *A B* is turned by the descent of the weight *w*, in the direction of the arrow, the catch acting in the teeth of the ratchet-wheel, the motion of *A B* is imparted by the action of the catch on the ratchet-wheel to the wheel *c d*, and by it to the hands.

Fig. 12.



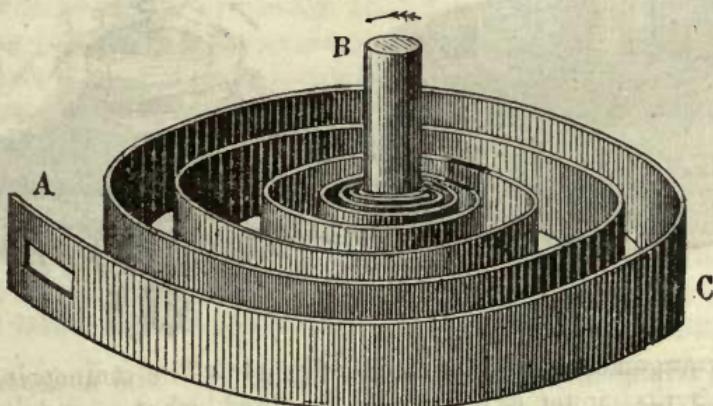
The form and mode of application of the ratchet-wheel will be presently more clearly explained.

30. The moving power of a weight can only be applied to time-

pieces where the space necessary for the play of the weight in its descent and ascent can be conveniently obtained. This condition is obviously incompatible with the circumstances attending pocket-watches, all portable and moveable timepieces, chimney, table, and console clocks, and in general all timepieces constructed on a small scale.

The moving power applied to these universally is a mainspring, which is a ribbon of highly tempered steel bent into a spiral form, as represented in fig. 12. At one end, A, an eye is provided, by which that extremity may be attached either to a fixed point or to the side of the barrel to which the spring is intended to impart motion. In the centre of the spiral an arbor, or axle, is introduced, to which the inner extremity of the spring is attached. Supposing the extremity A to be attached to a fixed point, let the arbor B (fig. 13), be turned in the direction indicated by the arrow. The spring will then be coiled closer and closer round the arbor A B, while its exterior coils will be separated one from another by wider and wider spaces.

Fig. 13.



After the spring has been thus coiled up by turning the arbor, it will have a tendency to uncoil itself and recover its former state, and if the arbor B be abandoned to its action and be free to revolve, it will receive from the reaction of the spring a motion of revolution contrary in direction to that which was given to the arbor in coiling up the spring, and such motion would be imparted to a wheel fixed upon the axle, and might from it be transmitted to the hands in the same manner as if the arbor-wheel received its motion from the power of a weight.

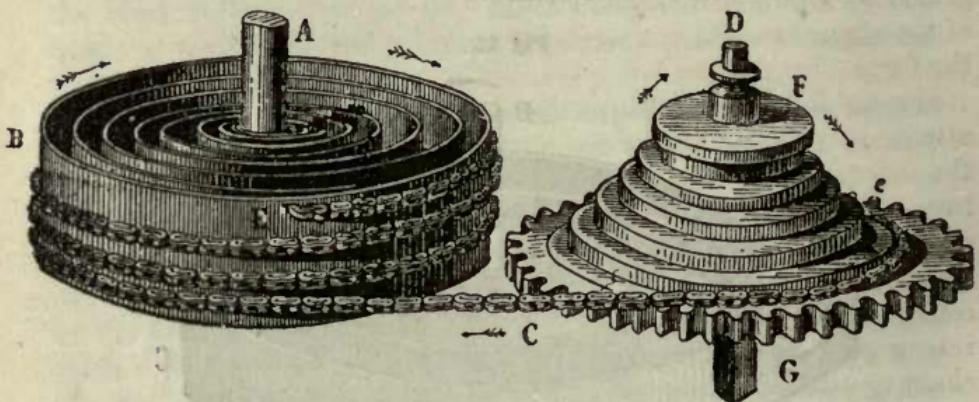
31. But between such a moving force and that of a weight there is an obvious difference. The tension of the cord by which the weight is suspended, and consequently its effect in giving revolution to the barrel upon which the cord is coiled, is always

the same until the clock altogether goes down. The moving force of the spring, on the contrary, is subject to a continual decrease of intensity. At first, when completely coiled up, its intensity is greatest, but as it turns the arbor *B* it becomes gradually relaxed, and its intensity is continually less and less. It exerts, therefore, a continually decreasing power upon the wheel fixed upon the arbor, and therefore upon the hands to which the motion is transmitted.

32. As a varying power would be incompatible with that uniformity and regularity which are the most essential and characteristic conditions of all forms of clockwork, such a spring would be quite unsuitable if some expedient were not found by which its variation could be equalised.

This has been accordingly accomplished, by a very beautiful mechanical contrivance, consisting of the combination of a flexible chain and a conical barrel arranged to receive its coils, called a FUSEE.

Fig. 14.



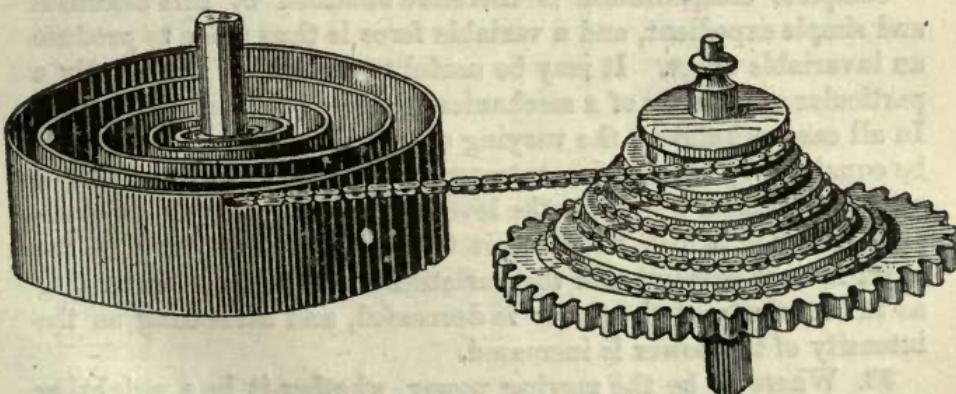
This arrangement is represented in fig. 14. The mainspring is attached by its inner extremity to the fixed arbor *A*, and by its outside end at *E*, to a barrel *B*, which is capable of being turned round the fixed axis *A*. A jointed chain is attached by one extremity to the barrel at *E*, and being coiled several times round it, is extended in the direction *C*, to the lowest groove of the fusee *E*, to which its other end, *e*, is attached. This fusee is a conical-shaped barrel, upon which a spiral groove is formed, continued from the base to the summit to receive the chain. The base is a toothed wheel, by which the motion imparted by the mainspring and chain to the fusee is transmitted to the hands through the wheelwork. The fusee is fixed upon an arbor, *D G*, the lower end of which, projecting outside the case containing the works, is formed square to receive a key made to fit it by which the clock or watch is wound up.

The action of the spring transmitted by the barrel to the chain, and by the chain to the fusee, has a tendency to impart to the fusee a motion of rotation in the direction of the arrows. The fusee is connected with the wheel, w, by means of a ratchet-wheel and catch similar to that described in the case in which the moving power is a weight, by means of which the fusee F imparts rotation to the wheel when it turns in the direction of the arrows, but does not move it when turned in the opposite direction.

These arrangements being understood, let us suppose the key applied upon the square-end G of the arbor D G of the fusee, and let it be turned round in the direction contrary to that indicated by the arrows. The fusee will then be turned, but will not carry the wheel w with it; the chain c will give to the barrel B a motion of revolution contrary to the direction of the arrows, the chain will be gradually uncoiled from the barrel B, and will be coiled upon the spiral groove of the fusee, winding itself from groove to groove, ascending on the spiral until the entire length of the chain has been uncoiled from the barrel B, and coiled upon the fusee F, as represented in fig. 15.

During this process, the external extremity of the mainspring, attached to the barrel at E, is carried round with the barrel, while the internal extremity is fixed to the arbor A, which does not turn with the barrel. By this means the spring is more and more closely coiled round the arbor A, until the entire chain has been discharged from the barrel to the fusee, when the spring will be coiled into the form represented in fig. 15, and in this state the intensity of its force of recoil, and the consequent tension of the chain c, extended from the barrel B to the fusee E, is greatest.

Fig. 15.



The clock being thus wound up and left to the action of the spring, the tension of the chain c, directed from the fusee to the

spiral, will make the fusee revolve in the direction indicated by the arrows. This tension at the commencement acts upon the highest and smallest groove of the fusee. As the chain is gradually discharged from the fusee to the barrel, the tension is gradually decreased by reason of the relaxation of the spring, and at the same time the chain acts upon a larger and larger groove of the fusee. In this way the tension of the chain is continually decreased, and the radius of the groove on which it acts is continually increased, until the entire action has passed from the fusee to the barrel, and the clock goes down.

Now the power of the chain to impart a motion of revolution to the fusee depends on two conditions; first the force of its tension, and secondly the leverage by which this tension acts upon the fusee. This leverage is in fact the semi-diameter of the groove, upon which the chain is coiled at the point where it passes from the fusee to the barrel. Without much mechanical knowledge it will be easy to perceive that it requires less force to turn a wheel or barrel if the force be applied at a great distance from the axle than if it be applied at a small distance from it. Upon this principle generalised, it follows that the power of the tension of the chain to impart revolution to the fusee is augmented in exactly the same proportion as the magnitude of the groove on which it acts is increased.

The form given to the fusee is such that as the chain is gradually discharged from it, the diameter of the groove on which it acts increases in exactly the same proportion as that in which the tension of the chain decreases. It follows, therefore, that the power of the chain upon the fusee gains exactly as much by the increase of its leverage as it loses by the decrease of its tension, and consequently it remains invariable.

Complete compensation is therefore obtained by this beautiful and simple expedient, and a variable force is thus made to produce an invariable effect. It may be useful to state that this is only a particular application of a mechanical principle of great generality. In all cases whatever, the varying energy of a moving power may be equalised by interposing between it and the object to be moved some mechanism, by which the leverage, whether simple or complex, through which its force is transmitted, shall vary in the exact inverse proportion of the variation of the power,—increasing as the intensity of the power is decreased, and decreasing as the intensity of the power is increased.

33. Whatever be the moving power, whether it be a weight or mainspring, it would, if not controlled and regulated, impart to the hands a motion more or less accelerated, and therefore unsuitable to the measurement of time, which requires a motion rigorously

BALANCE-WHEEL.

uniform. It is on that account that the moving power must be controlled and governed by some expedient, by which it shall be rendered uniform.

How the combination of a pendulum and escapement-wheel accomplishes this has been already explained. But this expedient requires that the timepiece to which it is applied shall be stationary; the slightest disturbance of its position would derange the mutual action of the pendulum and the escapement-wheel, and would either stop the movement, or permanently derange the mechanism. It is evident that a pendulum is not only inapplicable to all forms of pocket timepiece, but that it cannot even be used for marine purposes, the disturbances incidental to which would be quite incompatible with the regularity of its action.

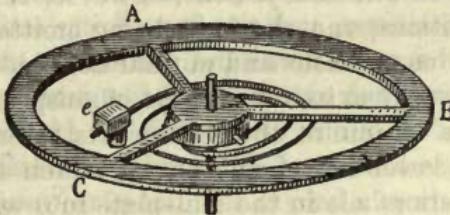
The expedient which has been substituted for it with complete success in all such cases is the balance-wheel.

This is a wheel, like a small fly-wheel, having a heavy rim connected with the centre by three or more light arms, as shown at A B C, in fig. 16. Under, and parallel to it, is placed a spring resembling in form the mainspring, but much finer and lighter, and having much less force.

This spring is formed of extremely fine and highly tempered steel wire, so fine that it is sometimes called a hair-spring. One extremity of this spring is attached to the axis of the balance wheel, and the other to any convenient fixed point in the watch. The spring is so constructed that when at rest it has a certain spiral form, to which it has a tendency to return when drawn from it on the one side or the other. If we suppose it, therefore, to be drawn aside from this position of rest and disengaged, it will return to it, but on arriving at it, having acquired by the elasticity a certain velocity, it will swing past it to the other side, to a distance nearly as far from its position of rest as that to which it had been originally drawn on the other side. It will then swing back, and will thus oscillate on the one side and the other of the position of rest, in the same manner exactly as that in which a pendulum swings on the one side or the other of the vertical line which is its position of rest.

34. The balance-wheel thus connected with a spiral spring, like the pendulum, is isochronous, that is, it performs all vibrations—long and short—in the same time. It will be recollect that this property of the pendulum depends on the fact that the

Fig. 16.



wider is the range of its vibrations the more intense is the force with which it descends to the vertical direction, and consequently wide vibrations are performed in as short a time as more contracted ones. Now the vibrations of the balance-wheel are subject to like conditions. The wider the range of its vibrations, the more intense is the force with which the recoil of this spring carries it back to its position of rest, and consequently it swings through these wide vibrations in the same time as through more contracted ones, in which the force of the spring is proportionally less intense.

The oscillation of the balance-wheel regulates the motion of watchwork in the same manner by means of an escapement-wheel, as that in which the pendulum regulates the motion of clock-work. The pallets and the escapement-wheel are, however, very variously formed in different watches.

35. Having thus explained generally the powers by which clocks and watches are moved and regulated, it now remains to show how the necessary motions are conveyed to the hands by suitable combinations of wheels and pinions.

In fig. 17 (p. 1), are represented the works of a common watch, moved by a mainspring A, and regulated by a balance-wheel H; the wheels and pinions, however, being changed in their relative positions, and the fusee being omitted, so as to show more visibly the connections and mutual dependency of the many parts. The external extremity of the mainspring is attached to the base, o, of a column of the frame. Its internal extremity is attached to the lower end of an axle, of which the square end, T, at the top enters a hole in the dial-plate into which the key is inserted when the watch is to be wound up. The ratchet-wheel B is fixed upon this axis so as to turn with it, but the other wheel c under the ratchet-wheel is not fixed upon it, the axis being free to turn in the hole in the centre of c, through which it passes. A catch n o is attached by a pin on which it plays to the face of the wheel c, and its point o is pressed against the teeth of the ratchet-wheel B, by a spring provided for that purpose. When the key is applied upon the end T, and turned in the direction in which the hands move, the ratchet-wheel is turned with it, and the point o of the catch—pressed constantly against the teeth while it turns—falls from tooth to tooth with an audible click, and thus produces the peculiar sound, with which every ear is familiar, while the watch is being wound up. During this process the wheel c does not turn with the axle, which only passes through the hole in its centre without being fixed upon it, but the mainspring, A, being attached to the axle is coiled more and more closely round it, and re-acts against the fixed point o with greater and greater force.

If the fusee, which is omitted in this figure, were introduced, it would occupy the place of the spring, and would be turned by the axle imparting a like revolution to the axis of the spring by means of the chain.

When the watch is wound up, the re-action of the spring, rendered uniform in its force by the fusee, imparts a motion of revolution to the ratchet-wheel *B*, in the direction of the arrow. By this motion the tooth of the ratchet-wheel in which the point *o* of the catch is engaged, presses against the catch so as to carry it round with it in the direction of the arrow ; but the catch being attached to the face of the wheel *c*, at *n*, this wheel is carried round also in the same direction, and with a common motion.

The teeth of the wheel *c* act in those of the pinion *d*, which is fixed upon the axle *d* *D*. Upon the same axle is fixed the wheel *D*, so that the wheel *D* and the pinion *d* receive a common motion of revolution from the wheel *c*.

The wheel *D*, in precisely the same manner, imparts a common motion of revolution to the pinion *e*, and the wheel *E* ; and the wheel *E* imparts a common motion of revolution to the pinion *f* and the wheel *F*.

This last wheel *F* is of the form called a crown-wheel, and acts upon the pinion *g*, imparting to it, and to the escapement wheel *G*, a common motion of revolution. This escapement-wheel is acted upon and controlled by the pallets or other contrivances attached to the axis of the balance-wheel *H*, so as to regulate its motion by the oscillations of that wheel in the same manner as the escapement-wheel of a clock is regulated by the anchor of the pendulum.

It may be asked why so long a series of wheels and pinions are interposed between the mainspring and the balance-wheel ? and why the first pinion *d* may not act directly upon the escapement-wheel ? The object attained by the multiplication of the wheels and pinions is to cause the mainspring, by acting through a small space, to produce a considerable number of revolutions of the escapement-wheel, for without that the spring would be speedily relaxed, and the watch would require more frequent winding up. Thus by the arrangement here shown, while the mainspring causes the wheel *c* to revolve once, it causes the pinion *d* and the wheel *D* to revolve as many times as the number of teeth in *c* is greater than the number in *d*. Thus if there are ten times as many teeth in *c* as in *d*, one revolution of *c* will produce ten of *d* and *D*. In like manner if *D* have ten times as many teeth as *e*, one revolution of *D* will produce ten of *e* and *E*, and so on. In this way it is evident that one revolution of the first wheel *c*, which is on the axis of the fusee, can be made by

COMMON THINGS—CLOCKS AND WATCHES.

mutual adaptation of the intermediate wheels and pinions, to impart as many revolutions as may be desired to the escapement-wheel *g*.

The wheels which govern the motion of the hands are those which appear in the figure between the watch face and the frame *xy*. The relative power of the mainspring and balance-wheel must be so regulated that the wheel *D* shall make one revolution in an hour. The axis upon which this wheel is fixed passing through the centre of the dial, carries the minute hand, which therefore revolves with it, making one complete revolution on the dial in an hour.

Upon this axle of the minute hand is fixed a pinion *k*, which drives the wheel *l*, on the axle of which is fixed the pinion *m*, which drives a wheel *p*, through the centre of which the axle of the minute hand passes without being fixed upon it. Upon the axle of the minute hand a small tube is placed; within which it can turn. Upon this tube the hour hand, as well as the wheel *p*, is fixed. The pinion *k*, therefore, fixed upon the axis of the minute hand, imparts motion to the hour hand by the intervention of the wheel *l*, the pinion *m*, and the wheel *p*. Since the hour hand must make one revolution while the minute hand makes twelve, it is necessary that the relative numbers of the teeth of these intermediate wheels shall be such as to produce that relation between the motions of the hands. An unlimited variety of combinations would accomplish this, one of the most usual being the following :—

Pinion <i>k</i>	8 teeth.
Wheel <i>l</i>	24 ,,
Pinion <i>m</i>	8 ,,
Wheel <i>p</i>	32 ,,

By this arrangement *p* will make eight revolutions, while *m* and *l* make thirty-two; or, what is the same, *p* will make one revolution, while *m* and *l* make four. In like manner, *l* will make eight revolutions, while *k*, and therefore the minute hand, makes twenty-four; or, what is the same, *l* will make four revolutions, while *k* and the minute hand make twelve. It follows, therefore, that *p*, and therefore the hour hand, makes one revolution, while *k*, and therefore the minute hand, makes twelve, which is the necessary proportion.

In this case there is no seconds hand: but, if there were, its motion would be regulated in like manner by additional wheels and pinions.

36. The manner in which the moving power of a weight, and the regulating power of a pendulum are applied in a clock to

MOVEMENT OF HANDS.

produce the motion of the hands, does not differ in any important respect from the arrangement explained above. Nevertheless, it may be satisfactory to show the details of the mechanism. The train of wheels connecting the weight with the anchor of the pendulum is shown in fig. 18 (p. 17).

A side view of the mechanism, showing the wheels which more immediately govern the motion of the hands, and also the pendulum, with its appendages, is given in fig. 19 (p. 33).

The weight *w* acts by a cord on a barrel, as already explained. This barrel and the ratchet-wheel, with its catch, are mounted upon the axis of the great wheel *c*, and are behind it, as represented in fig. 18, their form and position being shown by the white lines. The catch is attached to the wheel *c* by the screw *n*, and its point *o* acts on the teeth of the ratchet-wheel, which is attached to the barrel on which the rope is coiled. The spring which presses the catch against the teeth of the ratchet is also shown. When the clock is wound up by the key applied to the square end *r* (fig. 19) of the axis of the barrel, the barrel is turned in the direction opposite to that indicated by the arrows, and the catch falls from tooth to tooth of the ratchet-wheel, making the clicking noise which attends the process of winding up. When the clock has been wound up, the weight acting on the barrel presses the tooth of the ratchet-wheel against the catch, and thereby carries round with it the wheel *c*. This wheel transmits the motion to the escapement wheel *g*, fig. 17, through the series of wheels and pinions, *d*, *D*, *e*, *E*, *f*, *F*, and *g*, in the same manner exactly as has been already described (35); and the pendulum, by means of the anchor *NN*, regulates the motion in the manner described in 19.

The wheels which more immediately govern and regulate the motion of the hands are those which appear in fig. 19 in front of the plate *xy*.

The pendulum consists of a heavy disc of metal, seen edgeways at *v* in fig. 19, attached to the end of a metal rod, *RR*, represented broken, to bring it within the limits of the figure. This rod is suspended by various means, but often, as in the figure, by two elastic ribbons of steel, *ss*, which permit its swing right and left. It passes between the prongs of a fork *u*, by which a rod *rr* is terminated, so that this rod swings right and left with the pendulum. Upon the axis of this rod, and over the escapement wheel *g*, is fixed the anchor *N* of the escapement.

37. Whether the movement be regulated by a pendulum or a balance wheel, it is necessary to provide some means of adjustment by which the rate of vibration may be increased or diminished at pleasure within certain limits, for although in its original

COMMON THINGS—CLOCKS AND WATCHES.

construction the regulator may be made so as to oscillate *nearly* at the required rate, it cannot be made to do so *exactly*. Besides, even though it should vibrate exactly at the required rate, it will be subject, from time to time, to lose that degree of precision, and to vibrate too fast or *too* slowly from the operation of various disturbing causes.

It has been already shown, that the rate of vibration of the pendulum is rendered more or less rapid by transferring the centre of gravity nearer to, or farther from, the point of suspension. Upon this principle, therefore, the adjustment of the rate of vibration depends. The heavy disc v, fig. 19, is made to slide upon the rod RR, and can be moved upon it, upwards or downwards, by a fine screw attached to it, which works in a thread cut in the rod. In this manner the centre of gravity of the disc v may be transferred nearer to the suspension ss, so as to shorten the time of its vibrations, or removed farther from ss, so as to lengthen the time. If the clock is found to lose or go too slowly, it is screwed *up*, and if it gain or go too fast, it is screwed *down*.

In chimney and table time-pieces, the pendulum is regulated in a different manner. It is usually suspended upon a loop of silken thread, which can be drawn up or let down through a certain limited space, by means of a rod, upon which one end of the thread which forms the loop is coiled. This rod, passing through the dial-plate, has a square end, upon which a key can be applied, by turning which in the one direction or the other, the loop is drawn up or let down.

At bottom left margin: *the pendulum of a common pocket watch is suspended by a thin wire, which is wound round a small metal rod, which passes through the dial-plate, and is turned by a key, so as to shorten or lengthen the period of vibration.*

At bottom left margin: *The pendulum of a common pocket watch is suspended by a thin wire, which is wound round a small metal rod, which passes through the dial-plate, and is turned by a key, so as to shorten or lengthen the period of vibration.*

At bottom left margin: *The pendulum of a common pocket watch is suspended by a thin wire, which is wound round a small metal rod, which passes through the dial-plate, and is turned by a key, so as to shorten or lengthen the period of vibration.*

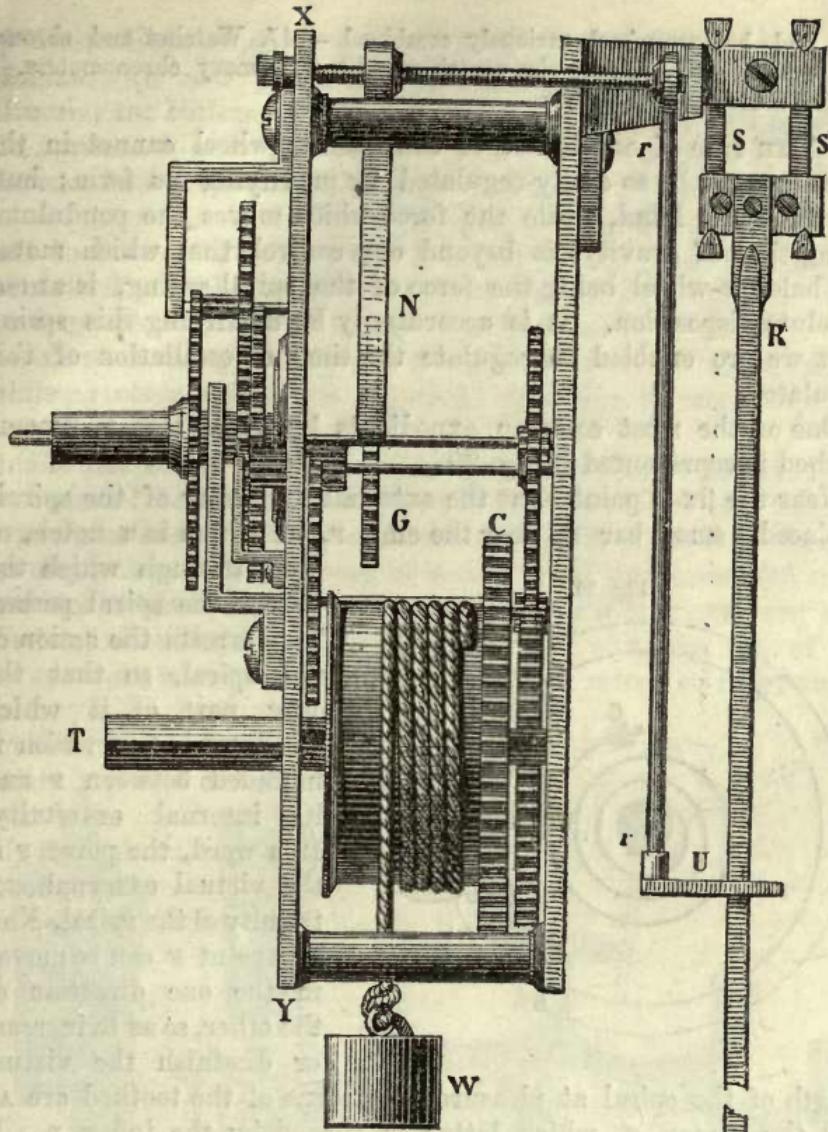


Fig. 19.

COMMON THINGS.

CLOCKS AND WATCHES.

CHAPTER III.

38. Method of regulating a balance-wheel.—39. Recoil escapement.—40. Cylindrical escapement.—41. Duplex.—42. Lever.—43. Detached.—44. Maintaining power of a clock moved by a weight.—45. Of a watch moved by a mainspring.—46. Weight or mainspring and pendulum

COMMON THINGS—CLOCKS AND WATCHES.

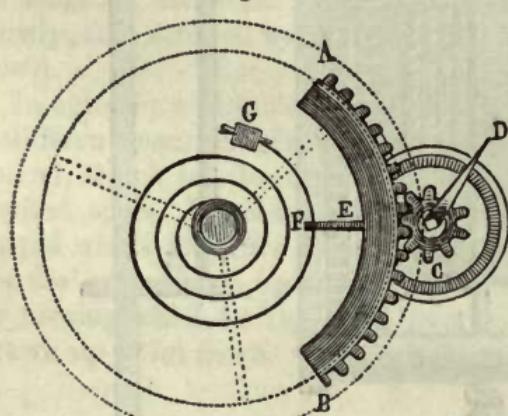
and balance-wheel variously combined.—47. Watches and chronometers.—48. Marine chronometers.—49. Stationary chronometers.—50. Striking apparatus.

38. THE rate of oscillation of the balance-wheel cannot in the same manner be so easily regulated by modifying its form; but, on the other hand, while the force which moves the pendulum, being that of gravity, is beyond our control, that which moves the balance-wheel being the force of the spiral spring, is at our absolute disposition. It is accordingly by modifying this spring that we are enabled to regulate the time of oscillation of this regulator.

One of the most common expedients by which this is accomplished is represented in fig. 20.

Near the fixed point *G*, at the external extremity of the spiral, is placed a small bar *E*, near the end, *F*, of which is a notch, or

hole, through which the wire of the spiral passes. This arrests the action of the spiral, so that the only part of it which oscillates is that which is included between *F* and its internal extremity. In a word, the point *F* is the virtual external extremity of the spiral. Now this point *F* can be moved in the one direction or the other, so as to increase or diminish the virtual



length of the spiral at pleasure, by means of the toothed arc *AB* and the pinion *c*, which latter is turned by the index *d*. If the index *d* be turned to the left, the bar *E*, and the point *f*, is moved towards *G*, and the length of the spiral is increased. If it be turned to the right, the point *F* is moved from *G*, and the length of the spiral is diminished.

In this manner the rate of vibration of the balance-wheel may be adjusted by varying at will the vertical length of the spiral-spring.

39. The precision of the movement of all forms of timepieces depends in a great degree on the mechanism of the escapement, and accordingly much mechanical skill and ingenuity have been directed to its improvement, and several varieties of form have been adopted and applied.

The recoil escapement, represented in fig. 17, consists of two

CYLINDRICAL ESCAPEMENT.

pallets, which project from the axis of the balance-wheel at right angles with each other, one of which acts at the top, and the other at the bottom of the escapement-wheel *G*, the axis of which is horizontal and the wheel vertical. These pallets, as the balance-wheel oscillates, engage alternately in the teeth of the escapement-wheel exactly in the same manner as do the pallets of the anchor of the escapement attached to the pendulum already described. This form of escapement was long the only one used, and is still continued in the more ordinary sorts of watches.

It has, however, been superseded, in watches and chronometers where greater precision is required, by others of more improved construction.

40: In pocket watches, where great flatness is required, the cylindrical escapement is used, in which the axis of the balance-wheel, instead of having pallets attached to it, is formed into a semicylinder, having a sort of notch in it, as represented on an enlarged scale in fig. 21. The semicylinder *a b*, is cut away at *c*, through about half its height. The axis *A B*, fig. 22, of the escapement-wheel is vertical, and the teeth raised at right angles

Fig. 21.

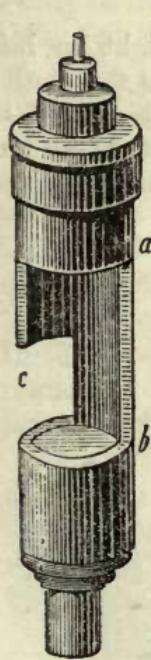
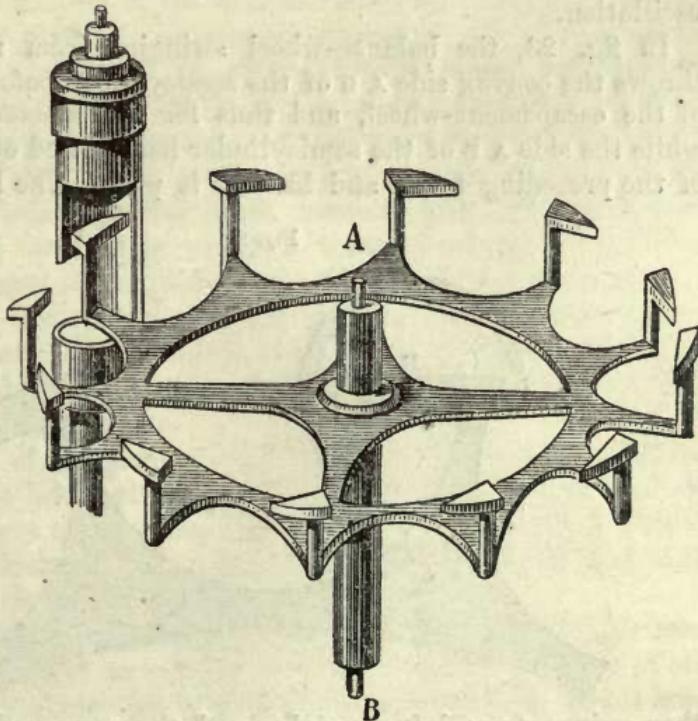


Fig. 22.

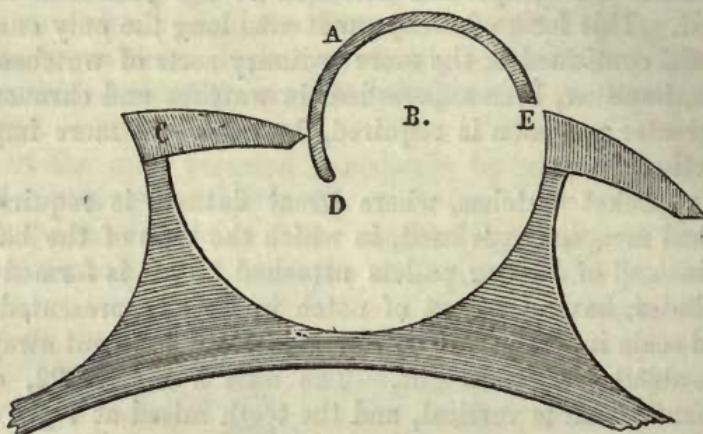


to its plane, and therefore parallel to its axis, have the peculiar form represented in the figure. As the balance-wheel oscillates on the one side and the other, the semicylinder upon its axis

COMMON THINGS—CLOCKS AND WATCHES.

interposes itself alternately between the teeth of the escapement-wheel, stopping them and letting them escape in the usual way. The manner in which the action takes place will be more clearly understood by the figures 23 and 24, in which a view in plan upon an enlarged scale is given of the position of the semicylinder

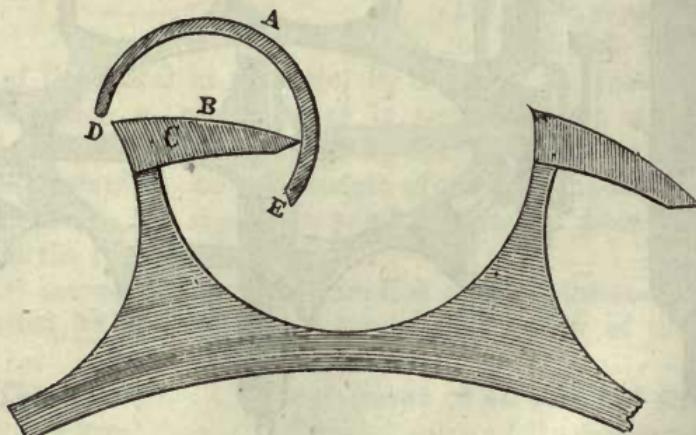
Fig. 23



and the teeth of the escapement-wheel after each successive oscillation.

In fig. 23, the balance-wheel swinging from right to left, throws the convex side $A\ D$ of the semicylinder before the tooth c of the escapement-wheel, and thus for the moment arrests it, while the side $A\ E$ of the semicylinder has turned out of the way of the preceding tooth and has let it pass. The balance-wheel

Fig. 24.



then swings from left to right, and the convex side $A\ D$ of the semicylinder slides against the point of the tooth c . When the edge D of the semicylinder passes the point of the tooth, the latter in slipping over it gives to it a slight impulse, which restores to

DUPLEX ESCAPEMENT.

the balance-wheel the small quantity of force which it lost by the previous reaction of the tooth upon its convex surface.

The side A E of the semicylinder is now thrown before the tooth c, the point of which having advanced through a space equal to the diameter of the semicylinder, is thrown against the concave surface of A E, as shown in fig. 24.

The balance-wheel now swinging again from right to left, the point of the tooth c slides upon the concave surface of the semi-cylinder A E, until the edge E comes to it. The tooth then slips over the inclined face of E, and in doing so gives the semicylinder and consequently the balance-wheel another slight impulse, restoring to it the force of which it deprived it while previously sliding upon its concave side.

The explanation here given of the action of this form of escapement is well calculated to render the conditions which all escapements should fulfil intelligible. These arrangements are primarily directed to the regulation of the movement of the wheel-work, so as to secure its uniformity. This will obviously be accomplished provided that the escapement, whatever be its form, lets a tooth of the wheel pass for each oscillation of the balance-wheel. But owing to the friction of the axis of the balance-wheel, and of the pallets on the teeth of the escapement-wheel, and the resistance of the air, the range of its oscillations would be gradually diminished, so that at last it would not be sufficient to allow the successive passage of the teeth of the escapement-wheel, and the watch would stop unless some adequate means are provided by which the balance-wheel shall receive from the mainspring through the escapement-wheel as much force as it thus loses. All escapements accomplish this by the peculiar forms given to the edges of the pallets and the teeth of the escapement-wheel. In the present case, the object is attained by making the edge D round and the edge E inclined, and by giving to the teeth the form shown in the figure.

This form of escapement supplies a sufficiently good regulating power for the best sorts of pocket watches, and is attended with the advantages of allowing the works to be compressed within a very small thickness. It is the form most commonly used in the French and Swiss watches.

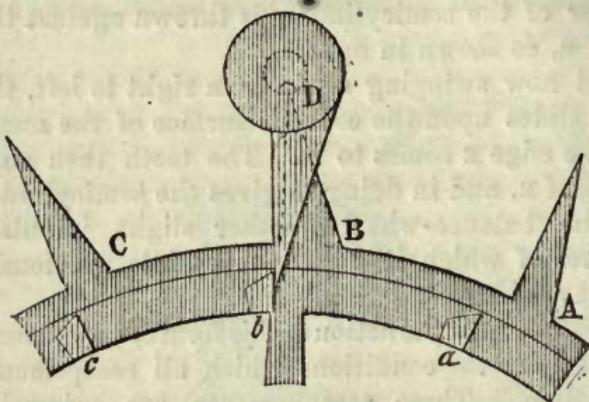
41. The form of escapement used in the best English made watches consists of an escapement-wheel, which partakes at once of the double characters of a spur and crown-wheel, and is hence called the duplex escapement.

The spur teeth, A, B, C, &c. (fig. 25), are similar in their form and arrangement to those of the cylindrical escapement described above. The crown teeth, a, b, c, &c., project from the face of

COMMON THINGS—CLOCKS AND WATCHES.

the wheel, and have a position intermediate between the spur teeth. Upon the axle of the balance-wheel just above the plane of the escapement-wheel is fixed a claw pallet called the impulse pallet, which by the combination of the oscillations of the balance and the progressive motion of the escapement - wheel falls successively between the crown-teeth of the latter, receiving from their reaction as they escape

Fig. 25.

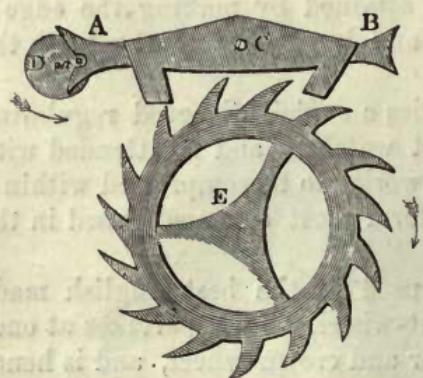


from it, the restoring action which maintains the range of the oscillations of the balance-wheel.

Under the pallet and in the plane of the spur teeth is placed a small roller usually formed of ruby or other hard stone, having a notch on one side of it, into which the spur teeth successively fall. After any crown tooth, *a* for example passes the pallet, the corresponding spur tooth *A* falls into the notch of the roller, and this alternate action continues so long as the watch goes. It will be perceived therefore that the pallet and roller in the duplex escapement play the same part as the two edges of the semicylinder in the cylindrical escapement, and as the two pallets in the common recoil escapement (fig. 17).

The chief advantage claimed for this system is that there is but

Fig. 26.



one pallet, and that the action does not require as perfect execution of the teeth of the escapement - wheel as other arrangements.

42. The lever escapement is much used for English pocket watches. A lever *A B* (fig. 26), with a notch at one end, is attached to the anchor *c*. A pin at *a*, on a disc *D*, on the verge or arbor of the balance, enters this

notch at each vibration, and first moves the dead part of the pallet off the tooth of the scape-wheel *E*, and then receives an impulse, which restores the force it has lost, leaving another tooth

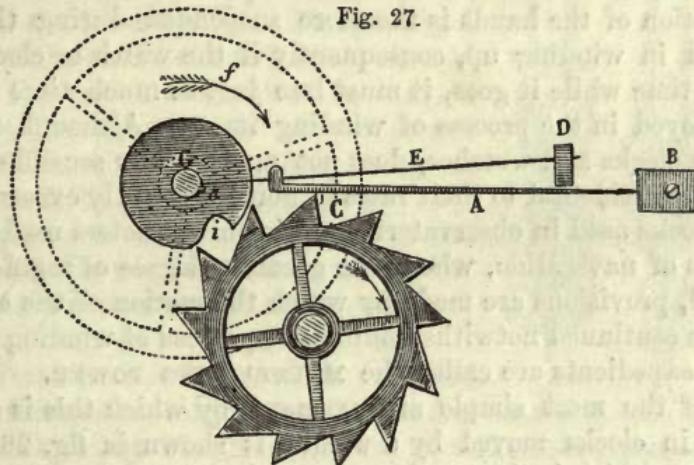
LEVER AND DETACHED ESCAPEMENTS.

engaged in the opposite pallet. As the lever is detached from the balance, except for an instant at the middle of each vibration, the amount of friction is very small. Another advantage of this movement is, that it is but little liable to derangement, and when it is injured, is easily and cheaply repaired, while the duplex and cylindrical escapements are expensive to make, and can only be mended by such skilful workmen as are not often found, except in the metropolis or large towns.

43. In the class of portable timepieces used for the purposes of navigation, where the greatest attainable regularity of motion is required, an arrangement is adopted called the detached escapement. This system is represented in fig. 27.

Upon the arbor of the balance-wheel is attached a disc, in which there is a notch *i*. A smaller disc, *g*, is also attached to it, from which a small pin projects. By the oscillations of the balance-wheel the notch *i* and the pin oscillate alternately right and left.

Fig. 27.



A fine flexible spring, *A*, attached to a fixed block, *B*, carries upon it a projecting piece, *c*. To the block *D* is attached another fine spring *E*, which extends to the edge of the small disc *g*. The projecting piece *c*, is so placed that when the spring *A* is not raised, it encounters a tooth of the scapewheel, but when slightly raised it allows the tooth to pass. The spring *E* rests in a small fork behind the extremity of *A*, and presented downwards.

Now, let us suppose the balance-wheel to swing from left to right. The pin, projecting from the small disc *g*, coming against the end of the spring *E*, raises it; and this spring acting in the fork behind it raises the spring *A*, and therefore lifts the piece *c*, and liberates the tooth which that piece previously obstructed. The scape-wheel therefore advances, but before the next tooth comes to the place occupied by the former one, the balance swings

COMMON THINGS—CLOCKS AND WATCHES.

back from right to left. The spring *E* no longer supported by the fork at the end of *A*, readily lets the pin pass, and the piece *C* returning to its former position, comes in the way of the succeeding tooth and stops it.

At the moment that the balance is about to commence its swing from left to right, and when the piece *C* is about to liberate the tooth which rests against it, another tooth behind it rests against the side of the notch *i* in the disc *G*, and when the escapement-wheel is liberated, and the swing of the balance from left to right is commencing, this tooth, pressing on the side of the notch *i*, gives it and the balance-wheel an impulse which is sufficient to restore to it all the force which it lost in the previous oscillation. Except at this moment the balance-wheel in this form of escape-ment is entirely free from all action of the mainspring.

44. While a clock or watch is being wound up, the weight or mainspring no longer presses upon the catch nor upon the ratchet-wheel, through which the motion is imparted to the wheelwork. The motion of the hands is therefore suspended during the time occupied in winding up, consequently if the watch or clock keep regular time while it goes, it must lose just so much time as may be employed in the process of winding it up. Although this, in common clocks and watches, does not produce any sensible effect, the errors incidental to their rates of going generally exceeding it, yet in clocks used in observatories and in chronometers used for the purposes of navigation, where the greatest degree of regularity is required, provisions are made by which the motion of the clock or watch is continued notwithstanding the process of winding up.

Such expedients are called the MAINTAINING POWER.

One of the most simple arrangements by which this is accomplished in clocks moved by a weight is shown in fig. 28. The weight *P*, which is the moving power, is connected with another much smaller weight *p*, by means of an endless cord which passes over the grooves of a series of pulleys, *A*, *B*, *C*, and *D*, of which *A* and *B* are moveable, and *C* and *D* fixed. The force with which *P* descends is the excess of its weight above that of *p*.

The pulley *C*, being prevented from revolving by the catch *E* during the descent of the weight *P*, and the cord being prevented from sliding upon its groove by the effects of its friction and adhesion, the parts *b a* and *c d*, which descend from the pulley *C* to the pulleys *A* and *B*, may be regarded as being virtually attached to fixed points at *b* and *c*, so that they cannot descend. This being the case, the weight *P*, descending by its preponderance over *p*, and consequently the weight *p* being drawn up, the part of the cord *c d* must pass over the pulley *B*, the part *e f* over the pulley *D*, and the part *g h* over the pulley *A*. In this

MAINTAINING POWER OF A CLOCK.

way the parts *b a* and *g h* will be gradually lengthened as the weight *P* descends at the expense of the parts *c d* and *f e*, which will be shortened to an equal extent, so that the weight *p* will be raised through the same space as that through which the weight *P* is lowered. During this process the wheel *D* is kept in constant revolution, and the first wheel of the train of clock-work being fixed on its axle, a motion is imparted by it through that train to the hands.

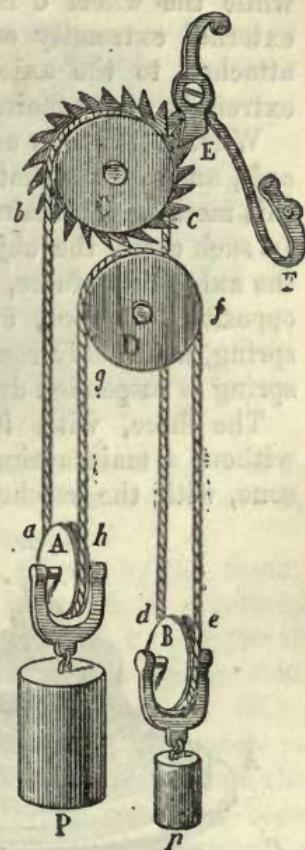
When it is desired to wind up the clock, the hand is applied to the cord *c d*, which is drawn downwards, so that the fixed pulley revolves, the catch *E* dropping from tooth to tooth until the weight *P* has been raised to the highest, and the weight *p* has fallen to the lowest point. The parts *g h* and *f e* of the cord not being at all affected by this, the pulley *D* continues to turn as before by the effect of the preponderance of *P*, which acts as powerfully while it ascends as it did when it descended.

It appears, therefore, that, by this arrangement, the motion of the works and of the hands is not suspended during the process of winding up.

45. If the works of a watch be impelled by the force of a mainspring without a fusee, in the manner represented in fig. 17, it is evident that the movement must be suspended during the process of winding up, because the ratchet-wheel *B*, by which the force of the spring is transmitted to the works, is then relieved from the action of the catch *n o*. This defect may, however, in such case be removed by a very simple expedient. Instead of connecting the external extremity of the mainspring with a fixed point, let it be attached to the inside of a barrel surrounding it, and let the wheel *c* be attached to this barrel. In that case, when the axle of the ratchet-wheel is turned in winding up, and the ratchet-wheel, therefore, relieved from the action of the catch, the wheel *c* will be acted upon by the barrel, which will itself be impelled by the reaction of the external extremity of the spring which is attached to it, the winding up being effected only by the internal extremity.

This is the arrangement generally adopted in chimney and table time-pieces, as constructed in France and Switzerland, and also in

Fig. 28.



COMMON THINGS—CLOCKS AND WATCHES.

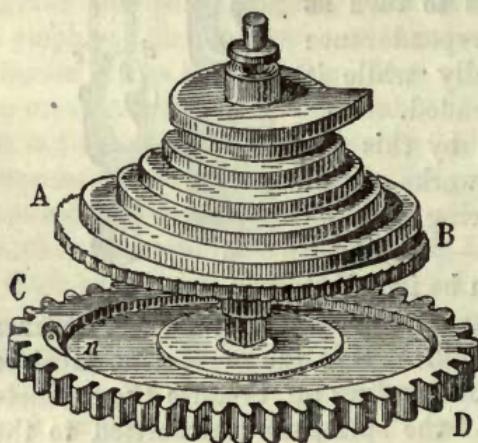
flat watches, in all of which the adoption of the cylindrical escape-movement (fig. 22) enables the constructor to dispense with the fusee.

It will, of course, be understood, that in such arrangements, while the wheel *c* is attached to the barrel, and by it to the external extremity of the mainspring, the ratchet-wheel *B* is attached to the axle *T B* (fig. 17), and by it to the internal extremity of the mainspring.

When a fusee is used, the ratchet-wheel being fixed upon its axis, and not on that of the barrel containing the mainspring, this method of obtaining a maintaining power is not applicable. In such cases, the object is attained by two ratchet-wheels upon the axle of the fusee, having their teeth and catches turned in opposite directions, one of them being impelled by a provisional spring, which only comes into play when the action of the mainspring is suspended during the process of winding up.

The fusee, with its appendages, as commonly constructed, without a maintaining power, is drawn in fig. 29, the grooved cone, with the ratchet-wheel attached to its base, being raised

Fig. 29.



from the cavity in the toothed wheel *c d*, in which it is deposited, to show the arrangement more clearly, and in the edge of which the catch *n* is placed, so that it shall fall into the teeth of the ratchet-wheel.

When the watch is being wound up, the chain passing from the barrel to the grooves of the fusee, the teeth of the ratchet-wheel, *A B*, pass freely round the cavity, the catch *n* falling

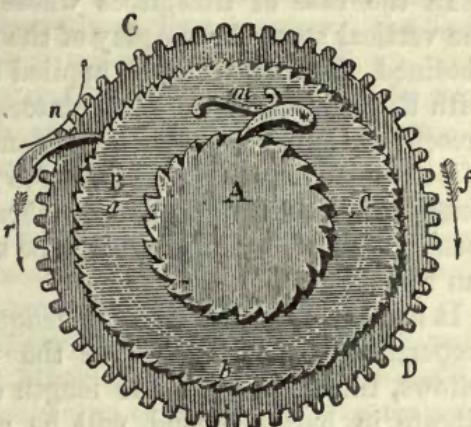
from tooth to tooth, and producing the clicking noise already noticed. But when the watch is going, the tension of the chain draws the fusee and the ratchet-wheel attached to it round in the contrary direction, and, pressing the teeth of the ratchet-wheel against the catch *n*, carries round the wheel *c d*, which gives motion to all the other wheels, and through them to the hands. Now, it will be evident, that when the watch is being wound up, and the catch *n* relieved from the pressure of the teeth of the ratchet-wheel, no motion will be imparted to *c d*, and consequently the movement of the entire works will be suspended.

The modification by which a maintaining power is obtained by the combination of two contrary ratchet-wheels, is shown in

MAINTAINING POWER OF A WATCH.

fig. 30, where $C D$ is the first wheel of the train from which the watch receives its motion. The ratchet-wheel A is fixed upon the base of the fusee, so as to move with it. The catch, m , which is pressed by a spring into the teeth of this ratchet-wheel, is attached to the second ratchet-wheel B , so that when A is carried round by the chain acting on the fusee, it must carry the wheel B round with it in the direction of the arrow f . The wheel B is connected with the wheel $C D$ by a semicircular spring $a b c$, which is attached to the wheel $C D$ at c , and to the wheel B at a . The catch, n , which falls into the teeth of the ratchet-wheel B , is attached to a fixed point on the bed of the watch.

Fig. 30.



While the watch is going, the wheel B , driven by the fusee, draws after it the spring $a b c$, bending it round to a certain extent, and this spring acting at c , on the wheel $C D$, draws it round in the direction of the arrow f . Now, let us suppose that the watch is being wound up. The ratchet-wheel A , being turned by the key in the direction of the arrow r , the catch m falls from tooth to tooth, and the force it before received from the ratchet-wheel A is suspended. But the spring $a b c$ has been drawn from its form of equilibrium, to a certain small extent, in drawing round after it the wheel $C D$, as already stated, and it has still a tendency to draw that wheel after it, so as to recover its form of equilibrium. In doing this, it will continue to act upon the wheel $C D$, and to carry it round while the action of the fusee upon it is suspended during the process of being wound up. The spring $a b c$ is so constructed as to act thus for an interval more than is necessary to wind up the watch.

46. From what has been explained, it will be observed, that timepieces in general are constructed with one or other of two moving powers, a descending weight, or a mainspring, and with one or other of two regulators, a pendulum or a balance-wheel. These expedients are variously adopted and variously combined, according to the position and circumstances in which the time-piece is used, and the purpose to which it is appropriated.

A descending weight as a moving power, combined with a pendulum as a regulator, supply the best chronometrical conditions. But the weight can only be used where a sufficient vertical space

COMMON THINGS—CLOCKS AND WATCHES.

can be commanded for its ascent and descent, and neither it nor the pendulum is applicable except to timepieces which rest in a fixed and stable position.

In the case of timepieces whose position is fixed, but where the vertical space for the play of the weight cannot be conveniently obtained, the mainspring is applied as a moving power, combined with the pendulum as a regulator. Chimney and table clocks present examples of this arrangement. The height being limited, it is necessary also in these cases to apply short pendulums. The length of a pendulum which vibrates seconds being about 39 inches, such pendulums can only be used where considerable height can be commanded.

It has been shown, that the lengths of pendulums are in the proportions of the squares of the times of their vibration. It follows, therefore, that the length of a pendulum which would vibrate in half a second, will be one-fourth the length of one which vibrates in a second, and since the latter is 39 inches, the former must be $9\frac{3}{4}$ inches. Such a pendulum can therefore be conveniently enough applied to a chimney or a table clock high enough to leave about ten inches for its play.

The pendulum is so good a regulator, and the anchor-escapement renders it so independent of the variation of the moving power, that in timepieces where it is combined with a mainspring a fusee is found to be unnecessary. In such cases, therefore, the axis of the first wheel is placed in the centre of the mainspring, as represented in fig. 17.

47. The cylindrical escapement, shown in fig. 22, is nearly as independent of the variation of the moving power as the pendulum, and therefore in common watches, where this escapement is used, the fusee is dispensed with.

In the class of timepieces called chronometers, used for the purposes of navigation, and in general for all purposes where the greatest attainable perfection is required in a portable timepiece, all the expedients to insure regularity are united, and accordingly the detached escapement is combined with fusee and mainspring.

Besides the expedients above mentioned, for insuring uniformity of rate, provisions are made in the most perfect chronometers to prevent the variations of rate which would arise from the expansion and contraction of the metal composing the balance-wheel by the variation of temperature. These expedients are very various; but in general they consist of contrivances by which the expansion of the rim of the wheel causes a part of it so to bend, as to throw a heavier part nearer to the centre, to compensate for the increased distance of another part produced by its general enlargement.

MARINE CHRONOMETER.

48. Marine chronometers are usually suspended in a box on gimbals, like those which support the ship's compass. The balance-wheel usually vibrates in half seconds, being a much slower rate than that of common watches. They are of immense utility in navigation, and especially in long voyages. See Tract on "Latitudes and Longitudes," Museum, vol. i. p. 97.

49. In observatories where stationary timepieces can be used, the clock moved by weights and regulated by a pendulum is invariably adopted. The pendulum, in such cases, is always so constructed that its rate of vibration shall not be affected by variations of temperature. This is accomplished usually by constructing it of two different kinds of metal, which are differently affected by heat, one being more expansible than the other. They are so arranged that the expansion of one shall elevate the centre of gravity, while that of the other lowers it, and the two effects are made to compensate each other, so that, however the temperature may change, the rate of vibration will remain the same.

50. In clocks adapted for domestic and public use, it is found desirable that they should give notice of the time, not only to the eye, but to the ear; and for that purpose a bell is attached to them, which tolls at given intervals, the number of strokes being equal to that of the units in the number expressing the hour. This appendage is called the STRIKING TRAIN.

The striking train, though connected with that which moves the hands, is quite independent of it, having its own moving and regulating power, and its own system of wheels by which the effect of the moving power is submitted to the regulator, and transmitted to the tongue of the bell.

Unlike the train which moves the hands, the striking train is not in continual motion. Its motion is always suspended, except at the particular moment at which the clock strikes. The mechanism partakes of the character of an alarum, being stopped by a certain catch until the hands point to some certain hour, and then being set free by the withdrawal of the catch. It remains free, however, only so long as is necessary for the tongue or hammer to make the necessary number of strokes upon the bell, after which the catch again engages itself in the striking mechanism, and stops it.

Some clocks only strike the hour. Others mark the half hours, and others the quarters, by a single stroke.

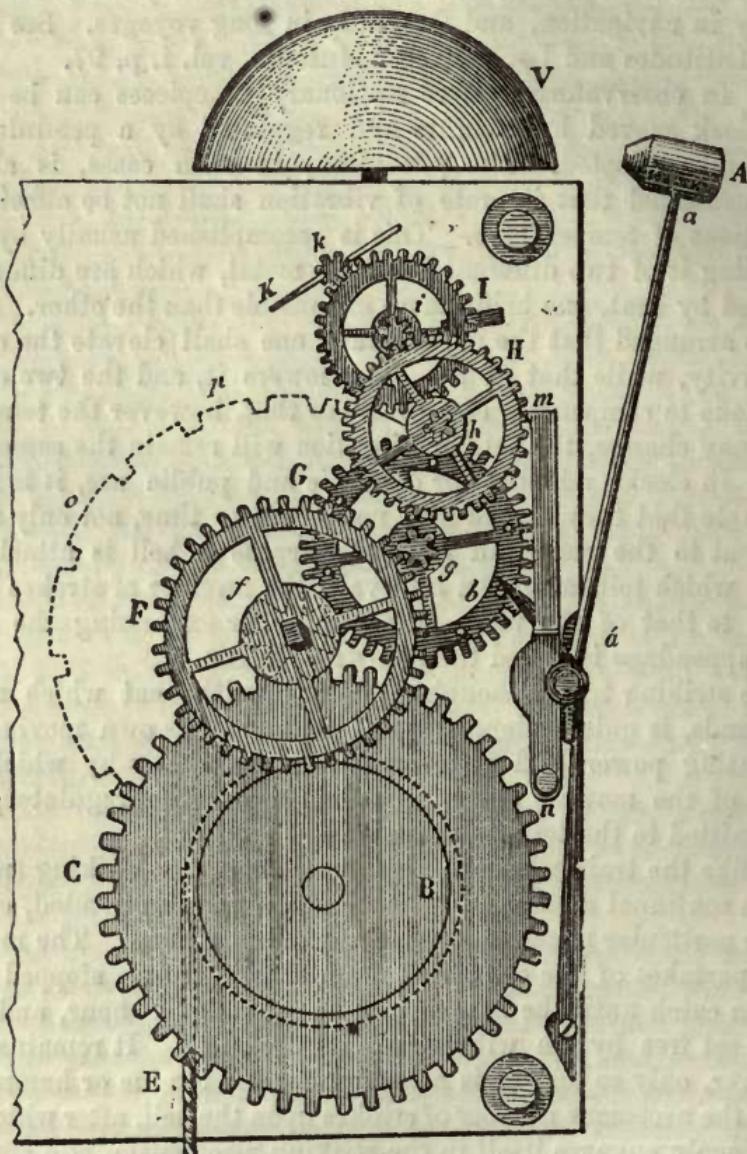
The general principle of the striking mechanism will be rendered intelligible by fig. 31, which represents it in the case of a common clock moved by a weight.

The weight suspended from the cord E moves the train in the same manner as in the case of the train which moves the hands. The motion of the first wheel, c, is transmitted to the last wheel, I,

COMMON THINGS—CLOCKS AND WATCHES.

which corresponds to the escapement-wheel by the intermediate wheels and pinions, *f*, *F*, *g*, *G*, *h*, *H*, and *i*. The wheel *r* drives

Fig. 31.



the pinion *k*, upon the axle of which is fixed the regulator *x*. This regulator is a fly, a side view of which, upon a larger scale, is shown in fig. 32.

The pinion, which is made to revolve by the wheel *w*, gives a motion of rotation to the fly *AA'B'B*, which consists of a thin rectangular plate of metal, along the centre of which the prolongation *M* of the axle of the pinion is attached. The flat surfaces of the fly, revolving more or less rapidly, strike against

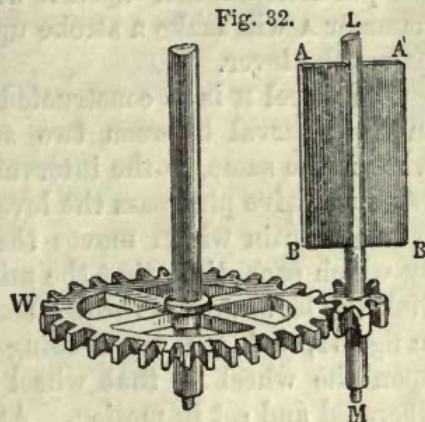
STRIKING APPARATUS.

the air, which resists them with a force which increases in the proportion of the square of the velocity of the rotation. Thus, if the velocity of rotation be increased in a two-fold ratio, the resistance to AA' B'B is increased in a four-fold ratio; if the rotation be increased in a three-fold ratio, the resistance is increased in a nine-fold ratio, and so on. It is evident, therefore, that by this very rapid increase, the resistance to the motion of the train must soon become equal to the descending force of the weight, and then the motion will become uniform; for if it were to increase, the resistance would exceed the force of the weight, and would slacken the rate of motion; and if it were to decrease, the resistance being less than the force of the weight, the latter would accelerate the motion. In either case the motion would immediately be rendered uniform.

Projecting from the face of the wheel H (fig. 31) there is a small pin which rests upon the end m of a lever $m\ n$, which turns upon the centre n . The lever $m\ n$ when in this position stops the motion of the striking train. Behind the same lever $m\ n$, and projecting from it, there is another piece, which in the position represented in the figure rests in a notch of the wheel $o\ p$, lying behind the striking train, and indicated in the figure by dotted lines. Around the edge of this wheel there is a series of similar notches at unequal distances, determined in the manner which we shall presently explain.

Upon the face of the wheel G , at equal distances one from another surrounding it, a series of pins project, which, as the wheel turns, successively encounter a lever b , which plays upon a centre a . Upon the same centre a is fixed the handle $a\ a'$ of the hammer A by which the bell v is struck. A spring fixed upon the same centre a causes the lever b to rest in the position represented in the figure, and to return to that position if raised from it. The hammer handle $a\ a'$ is made either elastic itself or is provided with a like spring.

When the wheel G is made to revolve at a uniform rate by the weight E , regulated by the fly x , the pins projecting from the face of the wheel G encounter successively the lever b , and raising it, throw back the handle $a\ a'$ of the hammer which is in connection with the lever b . After the pin has passed the lever b the latter is brought back with a jerk by the action of the spring, and the



hammer *A* receiving the same jerk strikes upon the bell *v* and instantly recoils from it; and if the wheel *H* continues to revolve, one pin after another upon it will encounter the lever *b*, and the hammer *A* will make a stroke upon the bell each time that a pin passes the lever.

The wheel *H* is so constructed that it will make one revolution in the interval between two successive strokes of the bell, or what is the same, in the interval between the moments at which two successive pins pass the lever *b*.

In the train which moves the hands, an expedient is provided by which each time that the minute hand passes twelve upon the dial, the lever *m n* is thrown back from the position which it has in fig. 31, and the top *m* being withdrawn from under the pin upon the wheel *H*, that wheel and the entire striking train is liberated and set in motion. At the same time the piece is taken out of the notch in which it rested on the wheel *o p*, and that wheel, in common with the other parts of the striking train, is put in motion.

For every complete revolution that the wheel *H* makes, the hammer *A* makes a stroke upon the bell, and the motion of *H* and of the entire striking train will continue until the end *m* of the lever *m n* again comes under the pin projecting from the face of *H*. During the motion, the lever *m n* is kept back by the edge of the wheel *o p* acting against the piece projecting from the lever *m n*. But when the wheel *o p* has turned so as to bring the next notch to the projecting piece, it will be thrown into the notch, and the end *m* of the lever *m n* coming under the pin projecting from the wheel *H*, the motion of the train will be suspended.

Now, it will be evident from what has been stated, that when the lever *m n* is thrown back by the works, it is kept back by the edge of the wheel *o p* acting against the projecting piece, and so long as it is thus kept back, the striking train continues to move and the hammer continues to strike the bell. But the duration of this motion will depend on the space between the notches on the wheel *o p*, since it is while that space upon the edge passes under the projecting piece on *m n* that the end *m* of the lever *m n* is kept back so as to be out of the way of the pin projecting from the wheel *H*. These spaces between the notches are therefore so proportioned, one to another, that the lever *m n* at each hour is held back a sufficient time for the hammer to make upon the bell the number of strokes denoting the hour and no more.

The arrangement for striking half-hours and quarters is based upon similar principles.

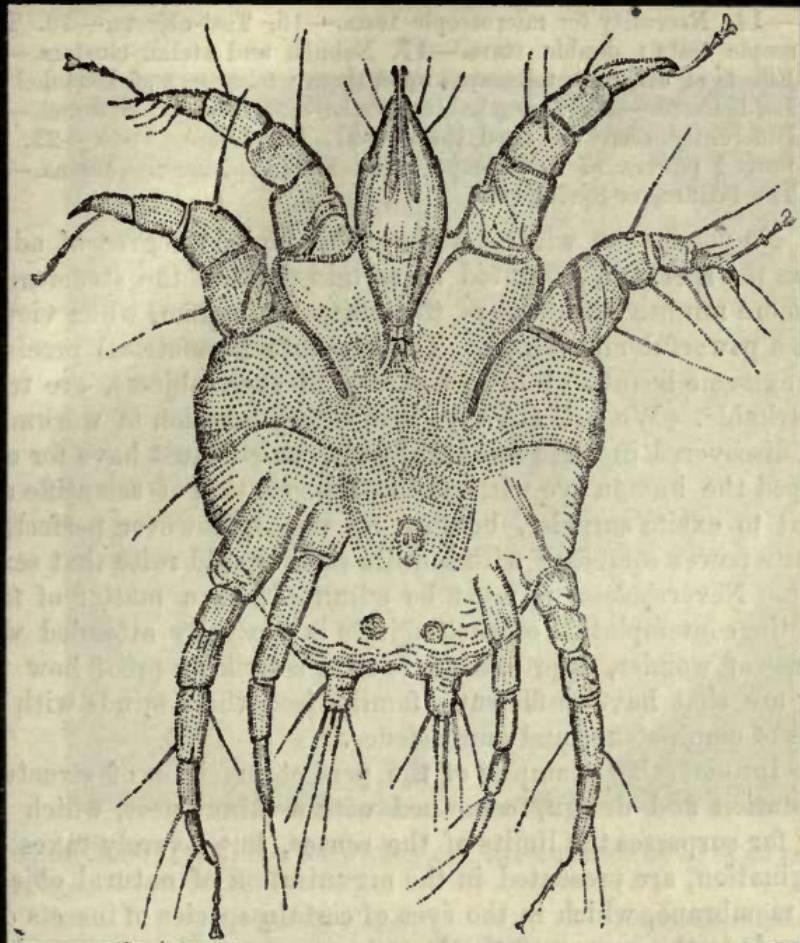


Fig. 37.—VIEW OF THE MANGE INSECT OF THE HORSE, MAGNIFIED 150 TIMES IN ITS LINEAR AND THEREFORE 22500 TIMES IN ITS SUPERFICIAL DIMENSIONS.

MICROSCOPIC DRAWING & ENGRAVING.

CHAPTER I.

1. Beautiful precision of the minute structure of natural objects.—2. Cornea of a fly's eye.—3. Number of eyes of different insects.—4. Astonishing precision of artificial objects.—5. Demand for such objects by Microscopists.—6. Classes of such artificial objects.—7. Microscopic scales.—8. Method of engraving them.—9. Measurement of microscopic objects with them.—10. Their minuteness.—11. Scales

MICROSCOPIC DRAWING AND ENGRAVING.

of Mr. Froment.—12. Rectangular scales.—13. Micrometric threads.—14. Necessity for microscopic tests.—15. Test-objects.—16. Telescopic tests; double stars.—17. Nebulae and stellar-clusters.—18. Effects of different telescopes upon them: telescopes of Herschel and Lord Rosse.—19. Remarkable nebulae described by Herschel.—20. Differently seen by Lord Rosse.—21. Microscopic tests.—22. Improved powers of microscope.—23. The *Lepisma-Saccharina*.—24. The *Podura*, or Spring-tail.

1. No person can witness without the highest degree of admiration the spectacle presented by certain parts of the structure of the more minute members of the animal kingdom, when viewed with a powerful microscope. The absolute geometrical precision and extreme beauty of design shown in such objects, are truly remarkable. We will not say, that such perfection of workmanship discovered in these minute objects, which must have for ever escaped the human eye without the intervention of scientific aid, ought to excite surprise, because no result, however perfect, of infinite power combined with infinite skill should raise that sentiment. Nevertheless, it must be admitted, as a matter of fact, that the contemplation of such objects is generally attended with a sense of wonder, approaching to awe, a striking proof how few they are that have sufficiently familiarised their minds with the ideas of omnipotence and omniscience.

2. Innumerable examples of the perfect precision of structure, adaptation and design, combined with a minuteness, which not only far surpasses the limits of the senses, but severely taxes the imagination, are presented in the organisation of natural objects. The membrane, which in the eyes of certain species of insects corresponds to the cornea of the human eye, presents an example of this. A very exact notion of this membrane, as it exists in the eye of the common house-fly, may be obtained by stretching a piece of bobbin-net over the surface of a billiard-ball: the ball with its reticulated hexagonal coating will then be a very precise model of part of the eye of the insect, upon a prodigiously magnified scale.

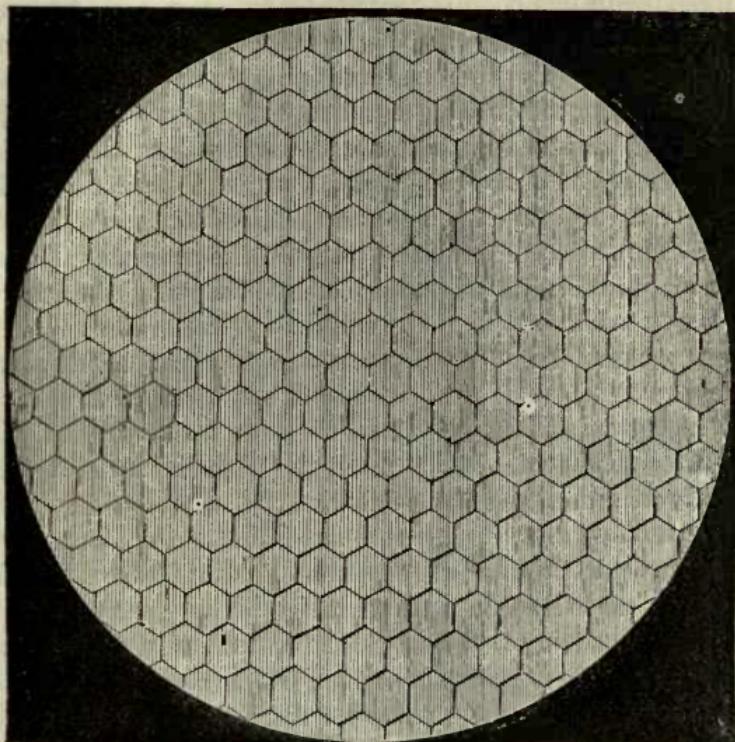
We have given in fig. 1 an engraving of this membrane, taken from a microscopic drawing, magnified 100 times in its linear, and therefore 10000 times in its superficial dimensions.

3. Each hexagon, as shown in the figure, is the cornea of a separate eye, having behind it the proper optical apparatus to produce the sense of vision. But it is more particularly to the minuteness of these beautifully precise hexagonal eyes, that I desire at present to direct attention. That minuteness will be most strikingly manifested by stating the number of these eyes with which different classes of insects are provided. According to the observations of various eminent naturalists, such as Swammerdam,

INSECTS' EYES.

Leuwenhoeck, Barter, Reaumur, Lyonnet, Paget, Müller, Strauss,

Fig. 1.



Dugès, Kirby, &c., the following are the number of eyes in certain species :—

	Number of eyes.		Number of eyes.
The Ant and the Zenos	50	|	The Cosus Ligniperda . 11300
The Sphinx . . .	1300	|	The Dragon Fly . . . 12544
The common Fly . . .	4000	|	The Butterfly . . . 17355
The Silkworm . . .	6236	|	The Mordella . . . 25088
The Cockchaffer . . .	8820		

4. But if the perfection found in the most minute workmanship of nature excite our admiration, how much more must we admire and wonder at the approaches which have been made to a similar degree of precision and perfection by the comparatively feeble and imperfect agency of the human hand. We propose in the present article to call the attention of our readers to some striking examples of such skill and address, with which the general public is not already familiar.

5. The improvements which have been made within the last quarter of a century, in the construction of microscopes, has created a demand for a class of drawings and engravings of a degree of minuteness approaching to that of the objects to which the researches of observers have been addressed. This

MICROSCOPIC DRAWING AND ENGRAVING.

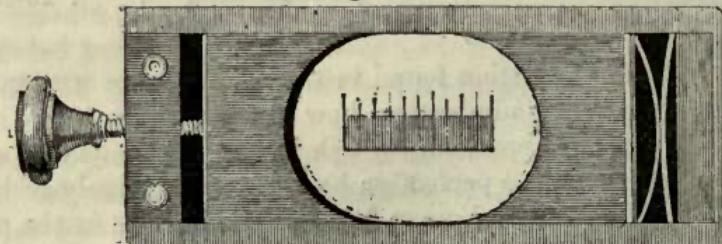
demand of Science upon Art has been adequately and admirably responded to.

6. Mechanism has been invented, by which minute tracings are made by a diamond point on the surface of glass ; such tracings being adapted to serve three distinct purposes :—1st. As standard measures of microscopic objects by superposition on them, just as ordinary lengths and breadths are determined by the application of the standard measure of yards, feet, and inches ; 2ndly, To serve as tests of the degree of excellence attained in the construction of microscopes, and as means of comparing the relative excellence of different microscopes, by observing the degrees of distinctness with which they enable the observer to see such minute tracings ; and, 3rdly, to serve for the production of microscopic engravings on its proper scale of any desired design.

This last process cannot be said to have been applied hitherto to any useful purpose other than the exhibition of an artistic *tour de force*, being, so far as relates to its means of execution, by far more difficult and ingenious than either of the former.

7. Microscopic objects are measured by divided scales of known dimensions ; their lengths and breadths being ascertained by the number of divisions of the scales on which they are placed, included between their limits or within their contour. Such scales, like larger measures, vary with the magnitude of the objects to which they are to be applied, but, even when largest in their divisions, are still very minute. They are generally traced upon small oblong slips of glass, the divisions being marked by fine parallel lines, every fifth division being a little longer than the intermediate ones, and every tenth still longer, as is shown on a greatly magnified scale in fig. 2.

Fig. 2.



8. The slip of glass upon which the scale is engraved is usually set in a brass framing, in which it is capable of sliding longitudinally, being pressed forwards in one direction by a fine screw, and in the other direction by the action of springs.

The diamond point by which the divisions are traced, is urged upon the glass, with a regulated pressure, so as to make traces so

MICROMETRIC SCALES.

even and uniform that no irregularity in their edges is discoverable by any microscopic power to which they are submitted. In the process of tracing the divisions, the point is moved over the glass, the latter being fixed, or the glass moved under the point by means of a very fine screw, called a micrometer screw, the magnitude of the thread of which is exactly known. The head of this screw is a metallic disc, fig. 3; the circumference of which is divided into from 200 to 400 equal parts, or even into a still greater number.

Let us suppose, then, the screw to be so fine that there are 50 threads to an inch, and the circumference of its head is divided into 100 parts; one revolution of the head will therefore move the screw and the diamond point upon which it acts through the one-fiftieth part of an inch. But if a fixed index be directed to the circumference of the head, so that the motion of the head through one division can be observed, such motion will move the diamond point through the 1-5000th of an inch.

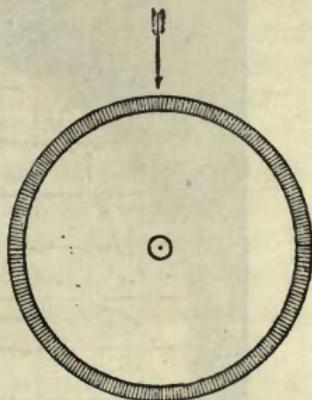
The cutter, after tracing each division, is raised from the glass, while the diamond point is pushed forward by the screw to the position necessary to engrave the next division of the scale, and proper mechanism limits the motion of the screw, so as to regulate the relative lengths of the divisions of the scale in the manner already explained.

9. A scale thus engraved, being viewed with a microscope whose magnifying power is proportionate to its minuteness, the divisions are rendered as distinctly visible as those of an ordinary rule are to the naked eye, and if the object to be measured be laid upon the glass its dimensions may be ascertained, as those of an object of ordinary size would be by a common rule.

10. These scales vary in the magnitude of their divisions, according to the magnitude of the objects which they are intended to measure. On those which have the largest divisions, an inch is divided into 500 parts; scales, however, are furnished by the opticians for microscopes in which an inch is divided into 2500 parts.

11. However minute such scales may seem, they are by no means the most minute that have been executed. Mr. Froment, whose apparatus for the division of astronomical instruments is well known, has supplied me with a scale in which a millimètre is divided into 1000 equal parts. Each division of this scale is, therefore, only the 1-25000th part of an inch.

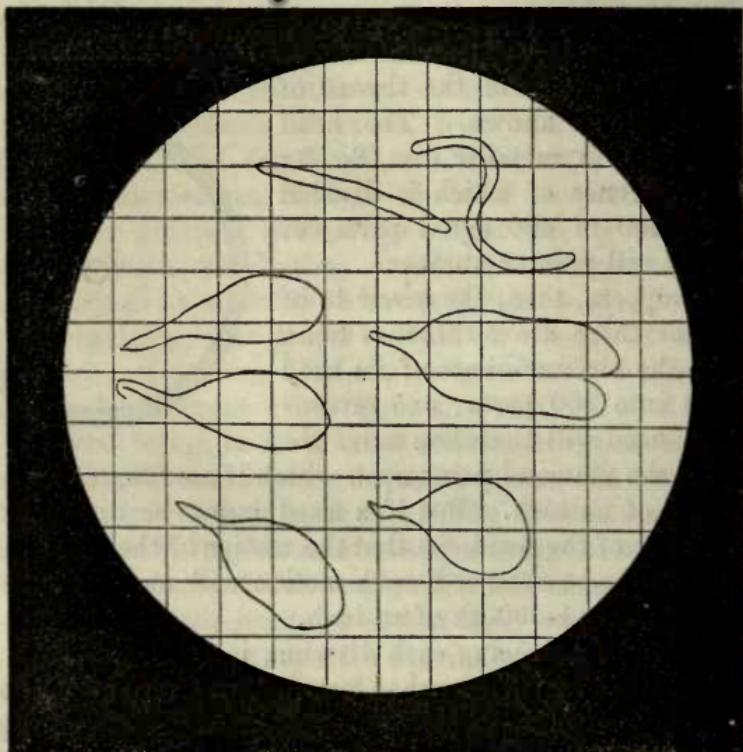
Fig. 3.



MICROSCOPIC DRAWING AND ENGRAVING.

12. Scales are sometimes engraved so as to indicate at once the dimensions of an object in length and breadth, by lines dividing

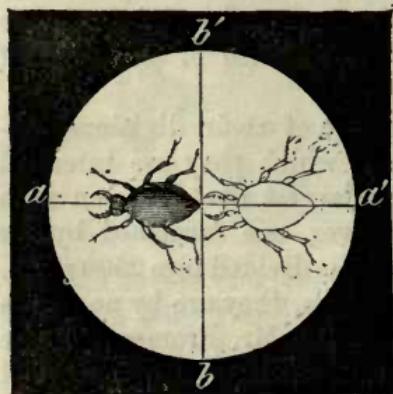
Fig. 4.



the glass in directions at right angles one to the other, as shown in fig. 4, upon a greatly magnified scale.

13. The dimensions of a minute object are sometimes ascertained by a somewhat different expedient.

Fig. 5.



projected on the object, as shown in fig. 5.

Arrangements are made by which, while the object is fixed,

USE OF TESTS.

the glass upon which the lines *a a'* and *b b'* are engraved, can be moved by a fine micrometer screw until the line *b b'* shall pass

Fig. 6.

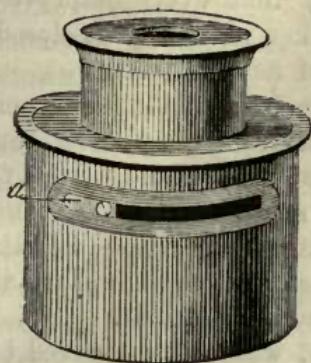
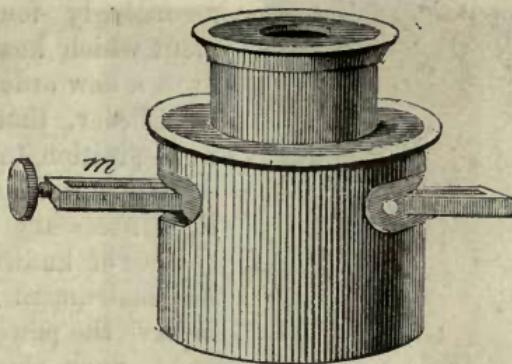


Fig. 7.



successively through the two extremities of the object, or the same purpose will be served, if, while the glass remains at rest, the stage which supports the object be similarly moved.

The number of threads of the screw to an inch being known, the number of revolutions and parts of revolutions of the screw necessary to make the line pass from one extremity to another, will give the length of the object, and a like process will determine its breadth.

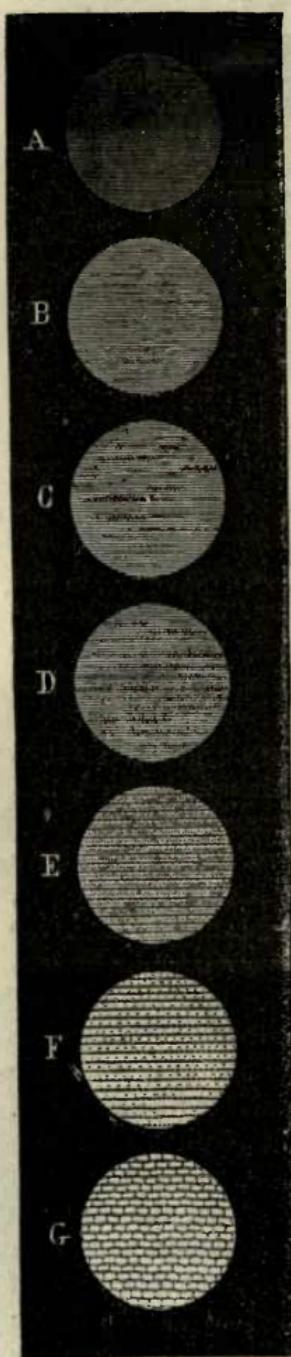
In the application of such scales to microscopic measurements, various practical precautions and expedients are necessary, which will be fully explained in our Tract on the Microscope.

14. Independently of being provided with means such as have been described above, for ascertaining the dimensions of objects, the advanced state of science renders it indispensable that the observer should possess means of testing the power of his instrument; without such means, he can never be sure that the appearance of the object, as presented by his microscope, corresponds with its real structure, or that important details of that structure may not escape his observation. A more striking example of this cannot be presented than one which was given by the late Dr. Goring, who showed that a particle of the dust taken from the wing of a certain species of butterfly, called the Morpho Menelaus, exhibited the seven different appearances shown in fig. 8; when viewed with the same microscope, the aperture of the object-glass and, consequently, the brightness of the image only being varied. It will be seen that details of structure are rendered apparent in *g*, where the aperture is greatest, which are very imperfectly shown in *f*, and not at all in those in which the aperture was still more limited.

MICROSCOPIC DRAWING AND ENGRAVING.

If, therefore, the observer were only supplied with a microscope, such as would have shown the object as exhibited at D, he would evidently have formed a very incorrect notion of its structure ; and it is accordingly found, that every improvement which has taken place has disclosed to us a new order of natural facts.

Fig. 8.



In order, therefore, to put the observer in a position to ascertain how far he can rely upon the indications of his instrument, it is necessary to supply him with some objects of known structure, whose details the instrument ought to make visible if it have the power which it claims.

15. Such objects, which have proved to be eminently useful in microscopic researches, and highly conducive to the progress of science, are called TEST-OBJECTS.

16. In the case of the telescope applied to astronomical researches, similar tests of efficiency are found in countless numbers in the heavens. Double, triple, and multiple stars are the most obvious examples of these. Such objects, as is well known, appear when viewed with the naked eye, or even with ordinary telescopes, as single stars ; but when instruments of superior power are directed to them they are RESOLVED, as it is called, and seen as what in fact they are, two or more minute stellar points in such close proximity, that the space between them is too small to affect the eye in a sensible manner, unless when magnified by artificial means.

17. Nebulae supply another order of telescopic test-objects. These appear, even when viewed with telescopes of considerable power, as small patches of whitish, cloudy light, of greater or less magnitude, a character from which they have received their name.

Such an object is represented, for example, in fig. 9.

When, however, a telescope of higher power is directed upon the same object, it will assume such an appearance as is shown

TELESCOPIC TESTS—NEBULÆ.

in fig. 10, a faint and rather indistinct indication of minute stars being perceptible; but when a still higher power is brought to bear upon it, the object will be seen as what it really is, a dense mass consisting of countless numbers of separate stars, as shown in fig. 11.

18. Different nebulae require telescopes of different powers, and many have never been yet resolved, even by the greatest powers that scientific art has yet produced. In proportion, however, as the telescopic power has been increased, more and more of these objects have been resolved. A remarkable illustration of this state of progressive discovery is supplied in the case of a well-known nebula, first observed and drawn by Sir John Herschel, as seen in a twenty-foot reflector. Sir John

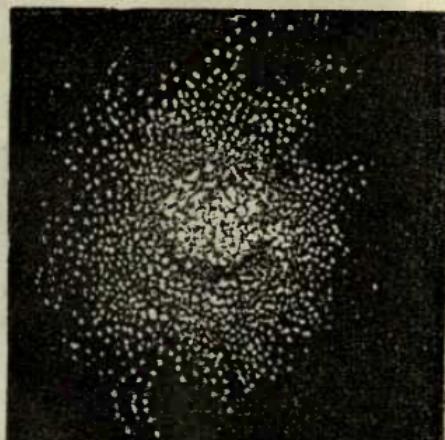
Fig. 9.



Fig. 10.



Fig. 11.



describes it as an object shaped like a dumb-bell, double-headed shot, or hour-glass; the elliptic outline being filled up by a more feeble and nebulous light, as shown in fig. 12, copied from the drawing of Sir John Herschel.

Such was the form and character assigned to this object until Lord Rosse had constructed larger and more powerful instruments, and when he directed upon it a twenty-seven foot reflector with three feet aperture, it assumed the appearance shown in fig. 13, where a faint indication of stars can be seen; subsequently,

MICROSCOPIC DRAWING AND ENGRAVING.

however, when he examined the same object with his great fifty-three foot telescope, having six feet aperture, it assumed the appearance shown in fig. 14.

19. Another very remarkable example of the change of appear-

Fig. 12.



ance produced in one of these wonderful objects, is presented in the case of a nebula first observed by Sir Wm. Herschel, and

Fig. 13.



described by him as a bright round nebula, surrounded by a halo or glory, and attended by a much smaller companion. Sir John

TELESCOPIC TESTS—NEBULÆ.

Herschel observed the same object, and discovered in it a very remarkable feature, which the telescope of his father had failed to disclose. This object, as drawn by Sir John Herschel, is shown in fig. 15. The separation in what Sir William Herschel called a

Fig. 14.



halo or glory, and what Sir John Herschel calls a ring, was the remarkable character which Sir John discovered. Sir John conjectured, from the general appearance of the object, that the central round nebula is a globular mass of stars, too distant to admit of being resolved by his telescope, and that what his father called a glory, is an annular mass of stars surrounding the former and split in the direction of its plane, so as to produce the appearance shown in the upper part of the figure.

Sir John conjectured that such stellar masses might have some analogy to the mass of stars which forms the milky way, and of which our sun is an individual unit.

20. How completely these speculations, ingenious as they were, were scattered to the winds, by bringing to bear on the same object a higher telescopic power, will be apparent by inspecting

MICROSCOPIC DRAWING AND ENGRAVING.

fig. 16, in which the same object is shown as it was afterwards seen with the great telescope of Lord Rosse.

Lord Rosse thinks that the brilliant convolutions of the spiral shown in his telescope, are identical with the split or divided part

Fig. 15.



of the ring as seen by Sir John Herschel, and he further observes, that with each increase of optical power, the structure of this object becomes more complicated and more unlike anything which could be supposed to result from any form of dynamical law of which we find a counter-part in our own system.

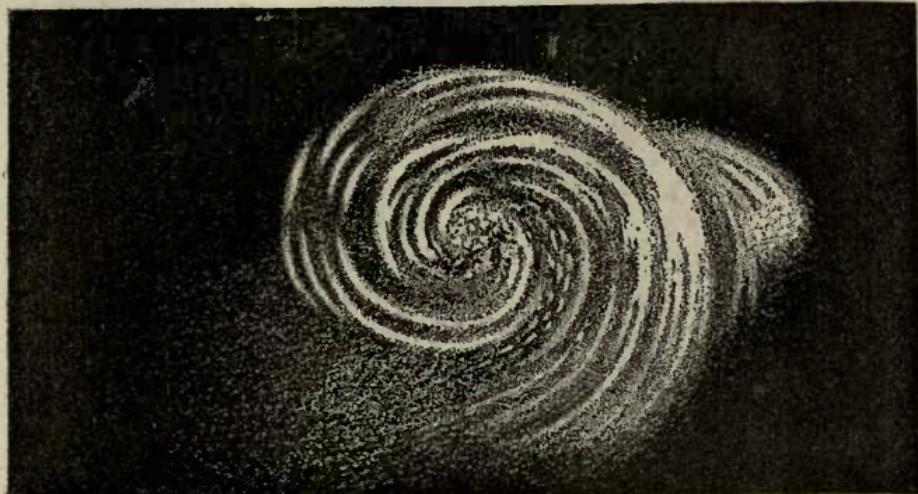
Before dismissing this very interesting subject of telescopic tests, we shall indicate one other, scarcely less remarkable. In fig. 17, is shown a small annular nebula, of a slightly oval form, observed and drawn by Sir John Herschel; the dark space in the centre of the ring he described to be filled with nebulous light, and that the edges were not sharply cut off, but were ill-defined, and exhibited a curdled and confused appearance, like that of a star seen with a telescope out of focus.

MICROSCOPIC TESTS.

The same object as seen with the more powerful telescope of Lord Rosse, is shown in fig. 18.

It is evident from this that very little more increase of optical

Fig. 16.

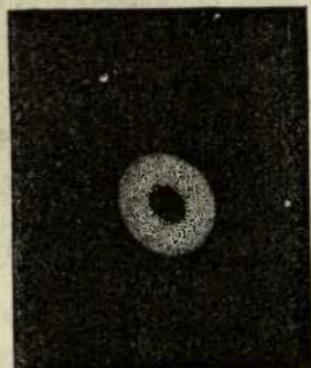


power would resolve this extraordinary object into an annular mass of stars.

21. Seeing then that the stupendous works of creation, existing in regions of space at measureless distances from the earth, have supplied such an unlimited variety of telescopic test-objects, it was natural to seek in other parts of creation where the more minute workmanship of nature has play for a corresponding series of microscopic test-objects. At the moment when that great and rapid improvement in microscopes was commencing, which was so powerfully promoted by the scientific and practical skill of the late Dr. Goring and Mr. Andrew Pritchard, it was found that various minute parts of the structure of certain species of insects could be rendered distinctly visible only by instruments possessing certain degrees of optical efficiency.

Dr. Goring, accordingly, selected a certain number of these objects, which he arranged in a graduated series, according to the microscopic powers required to render distinctly visible the details of their structure. These objects consisted chiefly of minute scales, detached from the bodies and wings of certain species of

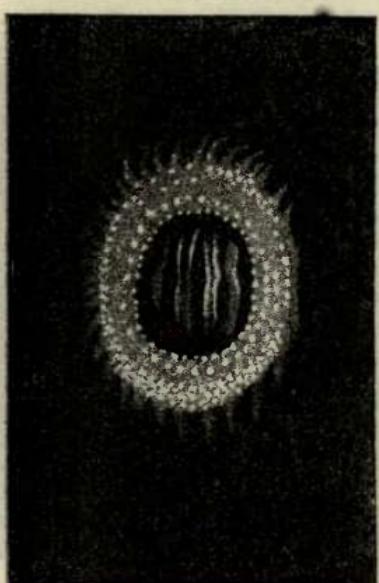
Fig. 17.



MICROSCOPIC DRAWING AND ENGRAVING.

insects; the striae and dots upon which could be seen with more or less distinctness, according to the excellency of the instrument.

Fig. 18.



It was to these that the name *test-objects* was first applied.

22. As the microscope has been improved in its power from year to year, these test-objects have increased in number; new details of structure being developed by every increase of power and efficiency in the instrument. A certain list of such objects has been agreed upon by general consent, and prepared for sale by the makers, consisting of hairs, scales, and feathers of insects; as, however, it is not my present purpose to enter into any explanation on the subject of microscopic tests, except so far as may be necessary to elucidate one of the uses of microscopic engraving, it will be

sufficient here to give a few examples of these test-objects.

23. There is a little insect, vulgarly called the *silver-fish*, or the *silver-lady*, of which the proper entomological name is the *Lepisma-Saccharina*; it is usually found in damp and mouldy cupboards, and in old wood-work, such as window-frames. The silvery lustre from which it takes its vulgar name, proceeds from a coating of scale-armour, with which its entire body is invested. These scales, when detached from the insect, and examined with a microscope, present a beautiful striated appearance; their magnitude varies; one, whose length is the 114th, and width the 170th part of an inch, is shown in fig. 19, as it appears in a good microscope, magnified 400 times in its linear, and therefore 160000 times in its superficial dimensions.

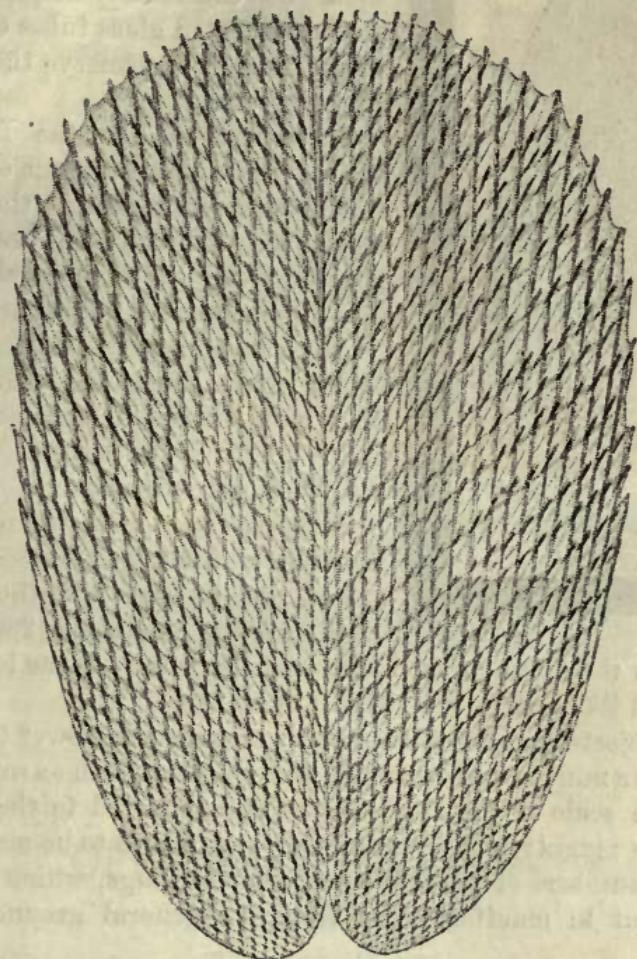
The scale, as here shown, is divided along the middle of its breadth, by a sort of geometrical axis, on either side of which the structure is perfectly similar. A regular series of striated lines diverge from this axis, at an angle of about 45° , intersected by another series, very nearly parallel to the axis.

The divergent striae are very slightly curved; the concavity being presented downwards, and the longitudinal ones ought to appear with a microscope to stand out in bold relief, like the ribs seen on certain shells; they are more closely arranged as they approach the lower part of the scale, and become more prominent as they are more separated in proceeding upwards.

LEPISMA AND PODURA.

Although the Lepisma is usually ranked among the test-objects, it must be observed that it is one of the lowest order, an instrument

Fig. 19.



of the most moderate efficiency never failing to render the striæ tolerably distinct.

24. The Podura, or common Spring-tail, is a little insect, generally found in great numbers in damp cellars, where they may be seen, running and skipping about upon the walls. Mr. Pritchard recommends the following method of collecting them: Sprinkle a little oat-meal or flour upon a piece of blackened paper, and place

MICROSCOPIC DRAWING AND ENGRAVING.

it near their haunts ; the meal serving the purpose of a bait, they will soon collect upon it; the paper may then be removed, and

Fig. 20.



being placed in a basin, should be brought into the light, when the insects will immediately jump from the paper into the basin: they should then be cautiously handled, and placed either in glass tubes or boxes with camphor, to preserve them from other insects.

These insects, like the *Lepisma*, are covered with an armour of scales, which, when submitted to the microscope, are found to be beautifully striated ; one of them is shown in fig. 20, magnified 550 times in its linear, and, consequently, 302500 times in its superficial dimensions. The real length of this scale was the 260th, and its extreme breadth the 700th, part of an inch.

Smaller, and still more finely marked, scales of the same insect are shown in fig. 21 ; the length of the greater being the 250th, and

its breadth the 500th, of an inch ; and the length of the lesser the 700th, and its breadth the 1375th, of an inch.

These objects require much greater microscopic power to render visible their minute and beautiful tracery, than such as would suffice for the scale of the *Lepisma*, when submitted to the highest practicable magnifying powers ; they are found to be marked by countless numbers of delicate cuneiform markings, which are seen to stand out in manifest relief from the general ground of the scale.

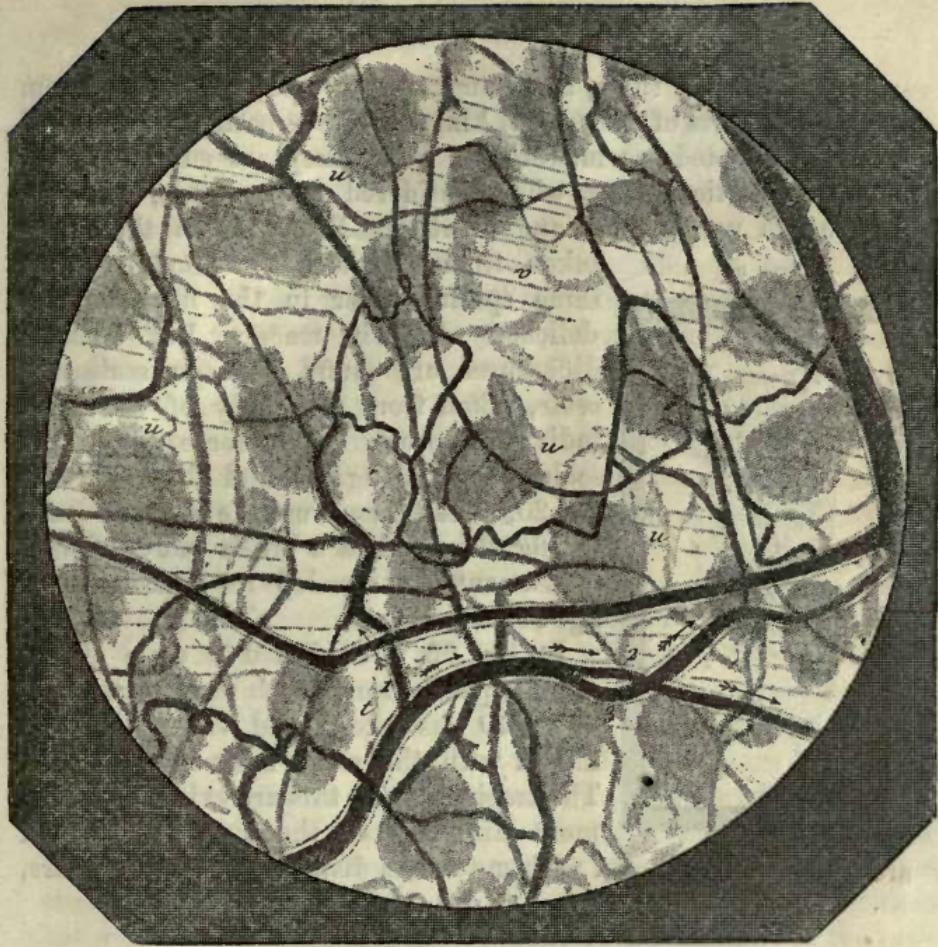


Fig. 39.—VIEW OF THE BLOOD-VESSELS AND OTHER PARTS IN A PORTION OF THE UPPER SURFACE OF THE TONGUE OF A FROG, THE REAL MAGNITUDE OF THE SURFACE DELINEATED BEING A CIRCLE THE 120TH OF AN INCH IN DIAMETER. DAGUERREOTYPED BY MESSRS. DONNÉ AND FOUCault.

MICROSCOPIC DRAWING & ENGRAVING.



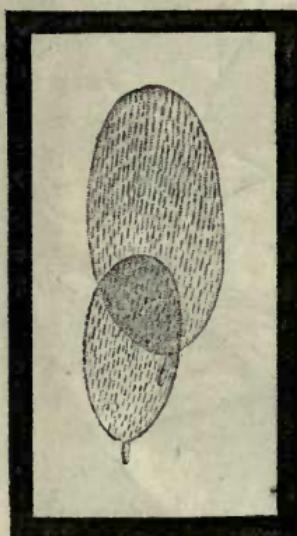
CHAPTER II.

25. Natural tests not invariable.—26. Natural tests imperfect standards.—27. Nobert's test-plates.—28. The degree of closeness of their lines.—29. Their use.—30. Apparent error respecting them.—31. Fronment's microscopic engraving.—32. Method of executing it.—33. Various methods of microscopic drawing.—34. Drawings by squares.—35. Dr. Goring's drawings.—36. Structure and metamorphosis of insects.—37. The day-fly.—38. The larva of this insect.—39. Its organs of respiration.—40. Its general structure.—41. Its mobility.—42. State of chrysalis.—43. The perfect insect.—44. The production and deposition of its eggs, and its death.—45. Death may be delayed by postponing the laying of the eggs.—46. They take no food.—47. Their countless numbers ; their bodies used as manure.

MICROSCOPIC DRAWING AND ENGRAVING.

25. ALTHOUGH these, and numerous other objects selected from the minute parts of the animal kingdom, have been proposed, and generally adopted, as microscopic tests; they are subject to the obvious objection, that, when considered as standards, they are wanting in permanence and identity. Not only do the scales

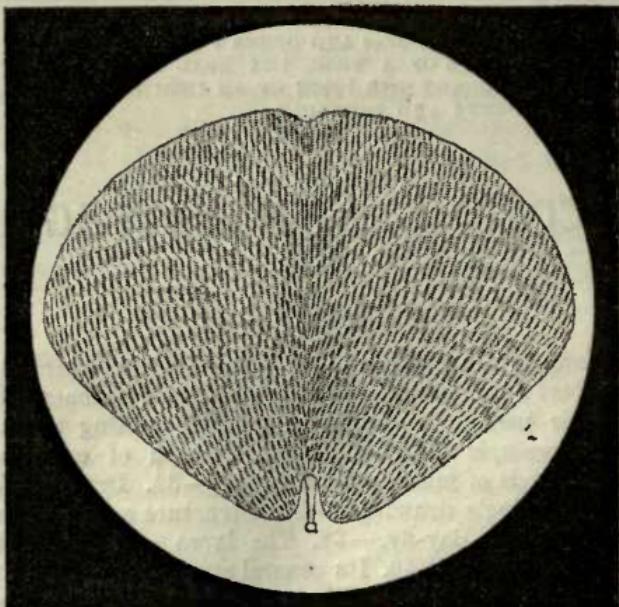
Fig. 21.



taken from different individuals of the same species differ in the fineness and delicacy of their tracery, but striking differences are found between scale and scale, taken from the body of the same individual insect. Thus, for example, the scales shown in fig. 21, and that shown in fig. 20, were taken from the same Podura, yet fig. 21 requires a much more efficient instrument to develop its tracery than fig. 20.

In fig. 22 is exhibited a scale of the same Lepisma from which that represented in fig. 19 was taken; and which has been drawn with the same magnifying power. The tracings upon this are evidently much more minute than those on fig. 19, and are consequently shown with much less distinctness. It appears,

Fig. 22.



therefore, that these two scales, taken from the same individual insect constitute different microscopic standards.

NOBERT'S TEST PLATES.

26. The erroneous estimates of the relative efficiency and power of different microscopic instruments which would result from the use of such test-objects, are obvious. A microscopist in London, observing the tracery of the scale of a Podura, and another at New York observing another scale of the same insect, the former failing to see its *striæ*, which would be visible to the latter, it could not at all be safely inferred, that the instrument of the one was inferior in efficiency and power to that of the other; and it might even happen, that the instrument which failed to show the *striæ* in London, was, nevertheless, superior to that which rendered them distinctly visible in New York. The result of such a comparison would entirely depend upon the structure of the two scales adopted as tests, which might differ within very wide limits.

Independently of this uncertainty attending the application of such tests, there is another not less serious objection to them; they hold out a temptation to microscope makers who supply them with the instruments they sell, to select such only as are most easily rendered visible; and although it be true that this is an expedient to which the most respectable class of makers would not resort, it is nevertheless true that the inferior makers do so, and thereby do injustice to those who are above such practices.

Natural objects, therefore, do not supply such permanent and unalterable tests for the microscope as the double stars, stellar clusters, and nebulae do for the telescope; and this circumstance has directed the attention of the higher class of artists, to the production of artificial test-objects which shall have determinate and certain qualities, and which, like manufactured articles, may be reproduced with such absolute identity as to supply standards of comparison that can be applied in different places, and at different times, to different instruments, so as to give results which will admit of comparison.

27. The production of micrometer scales, by Mr. Froment, the divisions of which are separated by intervals so small as the 25000th of an inch, has been already mentioned.

Now the lines marking such divisions being in closer proximity than those of the tracings upon certain test-objects, it will be evident that artificial test-objects might be made by means similar to those by which such scales have been executed, and there can be little doubt that the great artistic skill which has succeeded in producing traces, separated by the small interval above named, could be pushed further, so as to produce striated surfaces, which would serve all the purposes of test-objects.

Mr. Nobert, of Griefswall, in Prussia, has taken up this problem of test-objects, and, without attempting, as it would appear, to engrave micrometric scales, which would require intervals of some-

MICROSCOPIC DRAWING AND ENGRAVING.

exact aliquot part of a standard unit of length, has, nevertheless, produced bands engraved by a diamond point on slips of glass, consisting of a greater or less number of parallel lines, separated by intervals of surprising minuteness.

Some remarkable specimens of the production of this eminent artist were presented at the Great Exhibition in Hyde Park, in 1851. They consisted of ten bands, each composed of a certain number of parallel lines; those in each band being closer together than those in the preceding one. In the following table, we have given in the second column the number of lines which would fill the breadth of an inch in each succeeding band in one of these specimens.

I.	.	.	.	.	.	.	11265
II.	.	.	.	.	.	.	13142
III.	.	.	.	.	.	.	15332
IV.	.	.	.	.	.	.	17873
V.	.	.	.	.	.	.	20853
VI.	.	.	.	.	.	.	24309
VII.	.	.	.	.	.	.	28433
VIII.	.	.	.	.	.	.	33153
IX.	.	.	.	.	.	.	38613
X.	.	.	.	.	.	.	49910

Thus it appears that, in this specimen, the closeness of the ruled bands varied from 11000 to 50000 to the inch.

These bands are ruled on glass in parallel directions, being separated band from band, by comparatively wide intervals, so that, if sufficiently magnified, they present such an appearance as is shown in fig. 24. The highest band being that in which the lines are most separated, and the lowest that in which they are closest.

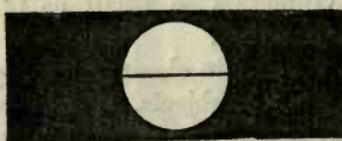
It is very difficult to convey a correct idea of the real appearance of this system of engraved bands before it is magnified; let us suppose, however, that fig. 23 represents the real magnitude of the

slip of glass upon which the engraving is made, and that the white circle in the centre is the part of the glass across which the series of ten bands, shown in a magnified form in fig. 24, are drawn. The entire space occupied by all the ten bands

will then be less in width than the black line which is drawn across the white circle in fig. 23. It must not be imagined that the white circle in fig. 23 represents that shown in fig. 24, the latter corresponds with a minute circular space in the centre of fig. 23, not much greater in diameter than the breadth of the black line.

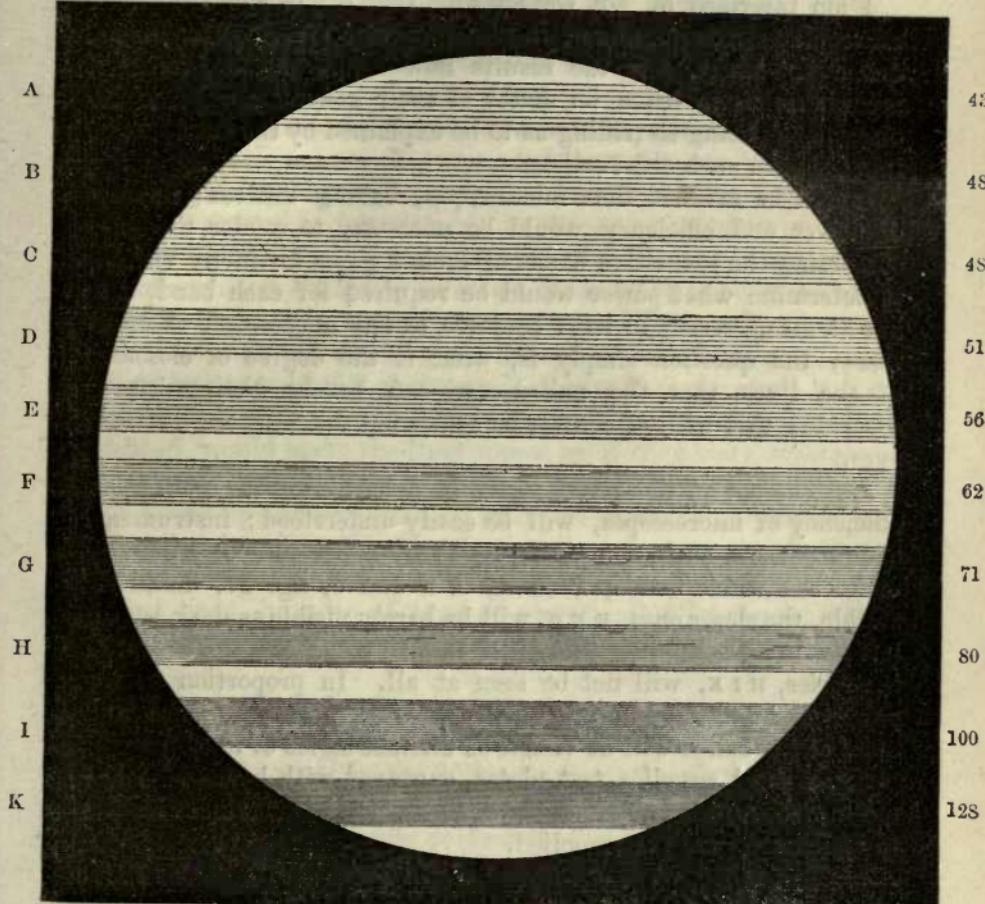
28. Various other test-plates have been engraved, and put in circulation by Mr. Nobert; I subjoin the analysis of one consisting

Fig. 23.



CLOSENESS OF LINES.

Fig. 24.



of 15 bands, which has been examined and calculated by Mr. De La Rue.

Series.	Number of lines.	Distance in relation to the English inch.	Number of lines in an Eng'ish inch.
1	7	0.00008880	11261
2	8	0.00007548	13248
3	9	0.00006482	15427
4	10	0.00005506	18162
5	11	0.00004884	20475
6	13	0.00004262	23463
7	15	0.00003552	28153
8	17	0.00003108	32175
9	19	0.00002664	37537
10	21	0.00002442	40950
11	23	0.00002220	45045
12	24	0.00002113	47326
13	26	0.00001998	50050
14	27	0.00001891	52882
15	29	0.00001776	56306

MICROSCOPIC DRAWING AND ENGRAVING.

I am informed by Mr. De La Rue, that bands engraved upon other plates, were observed and computed by himself, Mr. Lister, and Mr. Nobert, and the results now before me, are in such accordance as to leave no doubt of their general accuracy, the discrepancy being so trifling as to be explained by the small errors inevitable in such observations.

It will be evident that microscopes, having different degrees of power and efficiency, would be necessary to render the lines composing the successive bands of such a series distinctly visible; to determine what power would be required for each band, it is not at all necessary to have recourse to any microscopic observations; the question simply is, what is the degree of closeness of the lines, that the naked eye can barely distinguish as separate; this will, of course, be somewhat different for different eyes.

29. The use of these test-plates in determining the power and efficiency of microscopes, will be easily understood; instruments of low powers, such, for example, as from 100 to 200, will only make the wider bands, such as A B and c, fig. 24, distinctly visible, the closer ones, E F G, will be barely visible as dark bands, but the lines composing them will not be seen, and the closest of the series, H I K, will not be seen at all. In proportion as the power and efficiency of the microscope is increased, more and more of the bands will be visible as distinct series of lines.

Mr. Nobert supplies test-plates, engraved with bands of different degrees of closeness, according to the power of the instruments to which they are to be applied.

30. In the Report of the Juries of the Great Exhibition of 1851, page 268, it is stated, that to see the bands of a test-plate of 10 bands, such as that described above, a linear magnifying power of 100 is necessary for the wider bands, such as I and II, but that to distinguish those of the closest band, such as X, a magnifying power of 2000 is necessary.

I think it is apparent that this statement is erroneous, being evidently incompatible with the relative closeness of the lines of the several bands. Thus, for example, while there are 11265 lines of the first band to an inch, there are 49910 lines of the tenth band to an inch. Those of the latter are, therefore, only $4\frac{1}{2}$ times closer than those of the former; and it is evident, that if these bands be viewed with two microscopes, one having a magnifying power $4\frac{1}{2}$ times greater than that of the other, with proportional defining and illuminating powers, the lines composing them will appear equally separated; and since it is admitted in the report, that a power of 100 will render the lines of the first band visible, as it evidently will do, it will follow that

NOBERT'S TEST PLATES.

a power of 450 will render the lines of the tenth band equally visible; indeed, it is not necessary at all to have recourse to the microscope to ascertain the effect which a given magnifying power ought to produce upon a band of a given degree of closeness, since it is evident that the effect must be merely to make the lines composing the bands more widely separated than they are in the exact proportion of the magnifying power. Thus, if the lines composing a band, separated by intervals of the 10000th part of an inch, be viewed with the magnifying power of 100, they will appear as those of a band separated by intervals of the 100th of an inch; and if it be viewed with a magnifying power of 1000, it will appear as if the lines were separated by the 10th of an inch, and so on.

Now, let us apply this obvious principle to the case given in the report of the Juries; a magnifying power of 100 directed upon the first band, would make the lines appear as if they were separated by intervals of the 112th part of an inch; those of the second band would appear separated by intervals of the 131st part of an inch, and those of the third by the 153rd part of an inch. Now, all these would, as admitted in the report, be distinctly seen as separate lines, by eyes of average power. But let us see what effect a magnifying power of 2000 would produce upon the closest of the bands.

Since it would render the apparent intervals between line and line 2000 times greater than they are, those between the lines of the tenth band, would be the 25th; those of the ninth, the 19th; and those of the eighth, the 17th part of an inch.

Although it must be quite evident that such intervals are much greater than is necessary to enable any eye whatever that can see at all, to perceive the lines distinctly separated, the reader will be enabled better to appreciate the point by referring to the numbers which we have placed on the right of fig. 24, which express severally the number of lines to an inch in each of the bands composing that figure; thus, the lines of the bands *B* and *C* are separated by intervals of the 48th part of an inch; and it follows, therefore, that a magnifying power directed upon the band *x* of the test-plate, mentioned in the report of the Juries, would, if viewed by a power of 2000, show the lines separated by intervals twice as great, or equal to those of every other line in the bands *B* and *C*, fig. 24.

For these reasons, it appears to me that a mistake has been committed in the report of the Juries in this point, and I have thought it the more desirable to call attention to it, inasmuch as the statement has been reproduced in several recent works upon the microscope.

It is easy to show what would be the degree of closeness of the

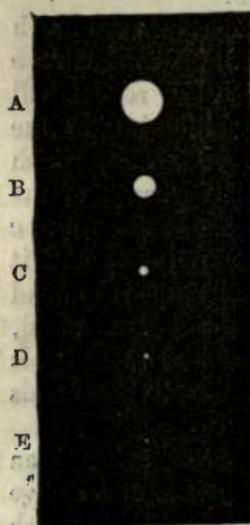
MICROSCOPIC DRAWING AND ENGRAVING.

lines composing a band, which a power of 2000 would barely render visible to average eyes. Assuming that such eyes could see distinctly without microscopic aid the lines of a band consisting of 150 to an inch, it is evident that a power of 2000 would render equally visible those of a band, the lines of which would be 300000 to an inch. I am not aware that Mr. Nobert, or any other artist, has ever produced such lines, and consequently doubt the existence of any such artificial test for a power of 2000.

31. I now come to notice a sort of microscopic engraving, which, though it is at once the most curious and difficult, has not, so far as I am informed, had as yet any directly useful application. Regarded, however, as an example of mechanical ingenuity and skill, and as an artistic *tour de force* of the highest order, it is full of interest.

However much we may admire the production of the micrometric scales and microscopic test-plates described above, there is nothing in them to excite surprise, save the precision which is combined with such extreme minuteness. To draw a series of parallel lines of regulated length and uniform intervals, is a problem, to the solution of which it is easy to conceive that finely constructed mechanism can be adapted; but when it is proposed to delineate objects and characters, in which no such regularity prevails, and, in tracing which, the point of the graving tool must pursue a course determined by conditions, which obviously cannot be represented

Fig. 25.



by any kind of mechanism, and to accomplish which it must be guided, directly or indirectly, by the hand, a problem of quite another, and far more difficult order, is presented: such, however, is the curious and complicated problem for which Mr. Froment, already named, has found a solution.

This eminent artist has succeeded in producing manuscripts and drawings, engraved upon glass, on a scale of minuteness in no degree less surprising, though far more difficult of execution than the test-plates of Mr. Nobert.

To enable the reader more easily to appreciate these wonderful productions, we have given in fig. 25 the forms and magnitudes of five small circular spaces, A, B, C, D, E, the diameters of which are severally the 6th, 12th, 30th, 70th, and 160th of an inch.

Mr. Froment wrote for me, in less than five minutes, within a

FROMENT'S MICROSCOPIC WRITING.

circle of glass, the 40th of an inch in diameter, less, therefore, by one third than the small white spot c, fig. 25 ; the sentence which, when magnified in its linear, 120, and in its superficial dimensions, 14400 times, presented the appearance shown in fig. 26.

Fig. 26.



On the occasion of the Great Exhibition in 1851, the characters and figures shown in fig. 27 were engraved by Mr. Froment, within a circular space equal to that shown at c in fig. 25.

32. As the method by which these marvellous effects are produced is not yet patented or made public, we are not at liberty to explain its details; but it may be stated generally to consist of a mechanism by which the point of the graver or style is guided by a system of levers, which are capable of imparting to it three motions in right lines which are reciprocally perpendicular, two of them being parallel, and the third at right angles to the surface on which the characters or design are written or engraved. The combination of the motions in the direction of the axis parallel to the surface on which the characters are engraved or written,

MICROSCOPIC DRAWING AND ENGRAVING.

determines the form of the characters, and the motion in the direction of the axis at right angles to that surface determines the depth of the incision, if it be engraving, or the thickness of the stroke, if it be writing.

33. Having thus explained the principal results of the art of microscopic engraving, it remains to offer some notice of the not

Fig. 27.



APPEARANCE AS SEEN IN THE FIELD OF THE MICROSCOPE, THE OUTER CIRCLE BEING ONLY THE 30TH OF AN INCH IN DIAMETER.

less interesting methods of delineating microscopic objects, or transferring to paper, metals, or wood fac-similes of the appearances presented in the microscope. The methods of accomplishing this have varied with the varying resources presented to art, by the progress of the sciences.

34. The first attempts at delineation of this kind were made by dividing the field of the microscope into a system of squares, by

DAY FLY.

means of micrometer threads or wires extended transversely to each other across the field of view, as shown in fig. 4. By this means, the field of view was, as it were, mapped out in squares, like lines of latitude and longitude, upon which the magnified images of the objects to be delineated were seen projected. The draftsman having previously prepared on paper a corresponding system of lines, transversely intersecting each other at distances, one from another, determined by the scale of the intended drawing, he proceeded to trace the outlines of the objects, guided by the correspondence between the system of squares upon his paper, and the system of squares seen in the microscope. The outlines being then obtained, which could always be most conveniently done with a low magnifying power, which would include at once within the field the entire object, or objects, to be drawn, the minute details of form and structure, were filled up within the outlines by viewing the parts of the object successively with much higher powers.

Neither this method, nor any other, depending on mere mechanical experience, would admit of being applied to the delineation of living objects, which are liable constantly to shift their positions and change their attitudes. To delineate these, the microscopist must also be an artist, and one of rather a high order; happily, the combination of the two qualities was not unfrequently found, and many beautiful representations, on a magnified scale, of the minuter members of the creation, have been supplied by the researches and talents of microscopic observers.

35. We shall select from these one or two admirable examples supplied by the late Dr. Goring; and it will not be unacceptable to the reader, if we accompany them with a brief account of the objects they represent.

36. For those who have not devoted attention to the history of the insect world, it may be well here to premise, that these little creatures are generally produced from eggs, and that, unlike all other members of the animal kingdom, they pass during their life through three stages of existence, in which their forms, habits, nourishment, and dwellings, differ one from another, for the same individual insect, as widely as do those of a crocodile and a peacock.

37. There is a certain little insect of the class of flies, called a day-fly, because the duration of its life, from the moment it attains the third and perfect stage of its existence never exceeds a day.

This insect deposits its eggs in water, well knowing, as it would seem, that its young, when hatched, are destined to be aquatic animals, although it is itself one of the gayest animals of the air.

MICROSCOPIC DRAWING AND ENGRAVING.

In due time, generally towards the decline of summer, the young, breaking the shell, issues from the egg in the form proper to the

Fig. 28.



first of the three stages of its existence, in which it is called a *larva*; its length, when full grown, in this state, is about half an inch, and it is represented in its proper magnitude in fig. 28. It is represented magnified in its linear dimensions $6\frac{1}{2}$ times; and, therefore, in its superficial dimensions, 42 times, in fig. 29.*

38. As the larva increases in size, the serpentine vessels attached to its sides become more apparent, and the tail assumes that rich feathered appearance which, in conjunction with the paddles projecting from its sides, constitute one of its most beautiful features.

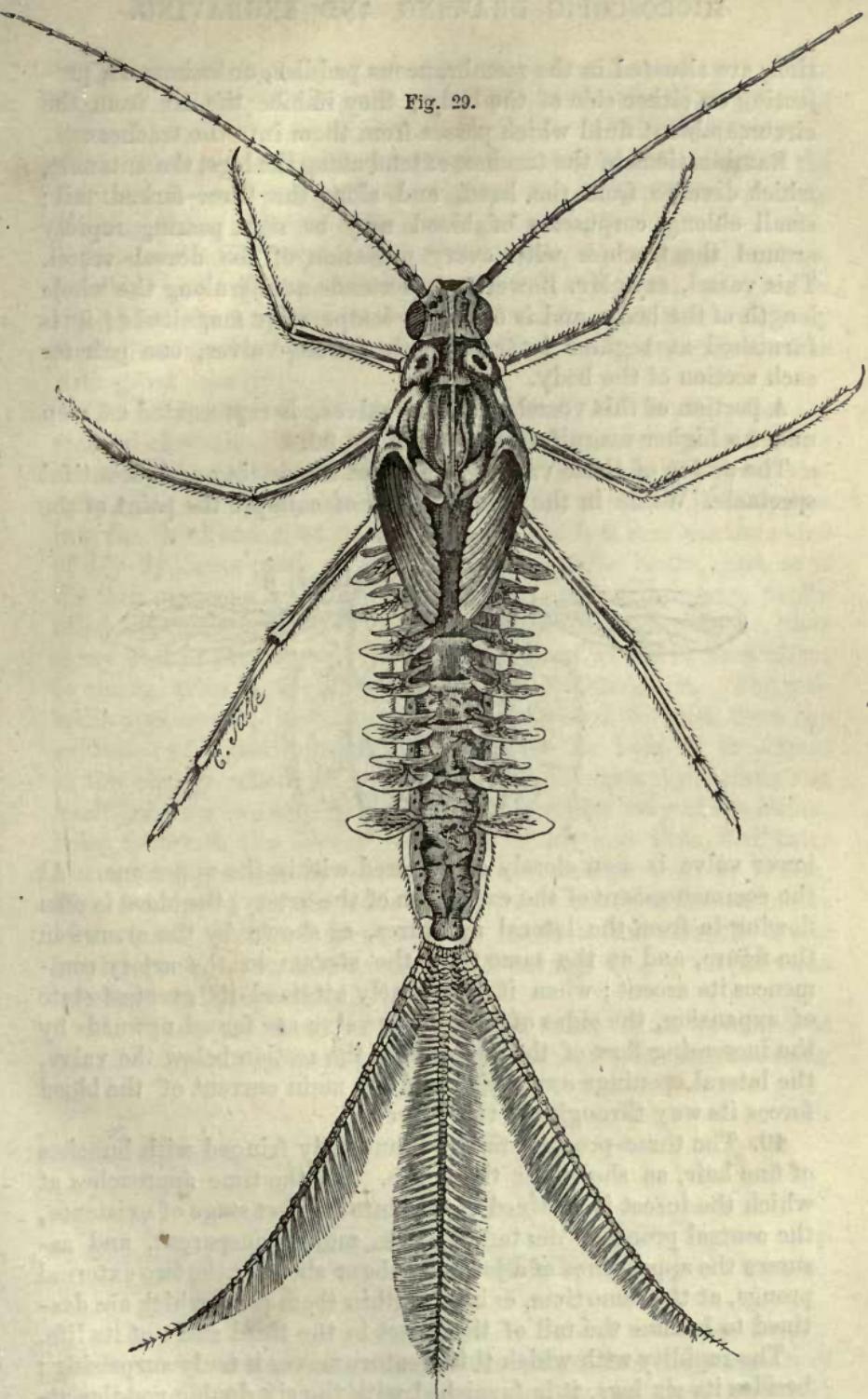
The body of the insect when young, being very pellucid, its internal organisation may be very clearly seen with the microscope by light transmitted through it. The peristaltic motion of the intestines; the circulation of blood, and the pulsations of the dorsal vessel, which in these creatures supplies the place of a heart, can be observed with the greatest facility. As it grows, it assumes a variety of colours, losing much of its transparency, when it is a few months old; at which time, the period approaches at which it is destined to pass into the second stage of its existence. The eyes, as will be seen in the figure, are large, protuberant, and curiously reticulated; they are of a citron colour. The body exhibits a beautiful play of various tints, finally assuming a rich brown colour, with various shadings.

39. It must be here observed, that the important function of respiration is performed in a very different manner, by different animals; the breathing apparatus being always admirably adapted to the element which they inhabit. The higher class of animals respire through the mouth and nose. Fishes take air through their gills, and insects through orifices provided for the purpose, either in the hinder extremity of their bodies, or along their sides. From these openings, the air passes through, and inflates vessels called tracheæ, which extend along their sides; in these it encounters the blood, on which it produces effects similar to those produced in the superior animals. These vessels appear in the figure running along each side of the body, and throwing out numerous ramifications which traverse the several leaf-shaped paddles projecting from the body.

The orifices by which air is supplied to the tracheæ for respira-

* This figure and the succeeding ones, drawn by Dr. Goring, have been copied with the permission of Mr. Pritchard from the microscopic illustrations.

Fig. 29.



MAGNIFIED VIEW OF THE LARVA OF THE DAY-FLY. DRAWN BY DR. GORING.

MICROSCOPIC DRAWING AND ENGRAVING.

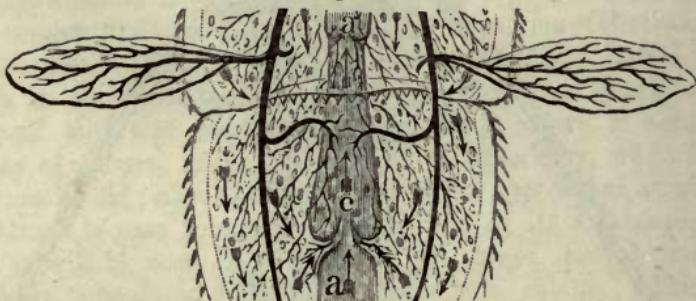
tion, are situated in the membranous paddles, or swimmers, projecting on either side of the body; they imbibe the air from the circumambient fluid which passes from them into the tracheæ.

Ramifications of the tracheæ extend along the legs, the antennæ, which diverge from the head, and along the three-forked tail; small oblong corpuscles of blood may be seen passing rapidly around the tracheæ with every pulsation of the dorsal vessel. This vessel, says Mr. Bowerbank, extends nearly along the whole length of the body, and is of great comparative magnitude; it is furnished at regular intervals with double valves, one pair for each section of the body.

A portion of this vessel, with its valves, is represented as seen under a higher magnifying power in fig. 30.

The action of these valves is a most interesting and beautiful spectacle. While in the greatest state of collapse the point of the

Fig. 30.



lower valve is seen closely compressed within the upper one. At the commencement of the expansion of the artery, the blood is seen flowing in from the lateral apertures, as shown by the arrows in the figure, and at the same time the stream in the artery commences its ascent; when it has nearly attained its greatest state of expansion, the sides of the lower valve are forced upwards by the increasing flow of the blood from the section below the valve, the lateral openings are closed, and the main current of the blood forces its way through the two valves.

40. The three-pronged tail is beautifully fringed with bunches of fine hair, as shown in the figure. As the time approaches at which the insect is destined to pass into its next stage of existence, the central prong of the tail becomes more transparent, and assumes the appearance of a jointed tube or sheath; the two external prongs, at the same time, exhibit within them parts which are destined to become the tail of the insect in the third stage of its life.

The rapidity with which this creature moves is truly surprising; besides its six legs, it is furnished with the six double paddles attached diagonally to the serpentine vessels on each side of its

THE PERFECT INSECT.

body, and with its tail, all of which it employs for rowing, balancing, and guiding itself in the water, the tail playing the part of the rudder.

41. Such is the mobility of these members, that even when the creature is in repose, all the paddles are in rapid motion ; the steering prong of the tail alone being at rest.

Independent of its faculty of locomotion by means of its legs, paddles, and tail, it possesses a power of leaping and springing in the water, by bending its body backwards, and then suddenly straightening it ; by this movement it raises itself to the surface with great celerity.

42. During the second stage of the life of this insect, called the state of chrysalis, it retains the faculty of swimming ; its motions are altogether subservient to its will, and it leaps with great alacrity. As the epoch, however, approaches at which it is to pass into the third and most perfect state, in which it receives the name of day-fly, some parts of it assume a metallic lustre, just as if the thin casing in which it is wrapped like a mummy, were partly filled with mercury ; this casing is so thin and translucent, that every part of the body of the perfect insect, which is soon about to emerge from it, is plainly enough visible through it. The metallic appearance, just mentioned, is supposed to arise from the evolution of a small quantity of gas from the body of the insect in the change which it is undergoing ; this gas, by insinuating itself between the case of the chrysalis and the body of the insect, helps to detach the former from the latter, and thus facilitates the natural process by which the insect emerges from its prison. The envelope of the chrysalis is adapted to the form and members of the insect, just as a glove is to the hand, so that after the insect has escaped from it, this envelope will exhibit with great precision its shape and proportions.

43. When the creature has divested itself of its envelope, it remains apparently inert for a few minutes on some neighbouring

Fig. 31.



plant, where it carefully cleanses its wings, and divests them of the last pellicle of the sheath in which they had been inserted ; it then assumes the beautiful form, and exercises the functions

MICROSCOPIC DRAWING AND ENGRAVING.

which appertain to it in the perfect state, and becomes the day-fly shown in fig. 31.

44. It now rises upon its wings into its new element, the air, where it joins tens of thousands of its fellows, who have almost simultaneously undergone a similar transformation. In the fine afternoons of summer and autumn, swarms of these creatures may be seen hovering in the air, all of them having emerged the same day from the state of chrysalis. Each female in these flights seeks its mate; which having chosen, they retire together to the leaves of some neighbouring plants. Immediately after their conjugal union, their proceedings are such as would be prompted by the tenderest parental solicitude for their future offspring, which, however, they are never destined to behold. Conscious, apparently, that their young must inhabit a very different element from that in which their short existence passes, they fly off in quest of water, in which, when found, the provident mother deposits her eggs, collected in a little packet in which they can float; the parents then abandon them to the warmth of the atmosphere, by which they are subsequently hatched, and having thus performed the last and most important duty of their life, that of increasing and multiplying their species, drop dead, the whole period of the existence of this gay insect being limited to a few hours of a summer afternoon.

45. So imperious is the will of nature in enforcing her laws, that if by artificial interference, the insect after emerging from the envelope of the chrysalis be prevented from joining its fellows and kept in solitude, its life will be prolonged far beyond its natural term, as if it lived only for the performance of the duty prescribed to it by its Maker. Dr. Goring ascertained this fact by catching a day-fly just emerged from the chrysalis, which he imprisoned for several days, during which it continued to live; he observed that in such cases the insect did not seem at all enfeebled, even when thus confined for a week, so that upon being liberated it flew briskly away, found its mate, produced and provided for its eggs, and immediately died.

46. It is remarkable that these little creatures, during their ephemeral existence, take no food; the only function they exercise being that of propagation.

47. It appears, that in some localities, these flies prevail in such countless numbers that their bodies are found after death covering the ground to a considerable depth, and they are collected in cart loads by the agriculturists, who use them for the purpose of manure.

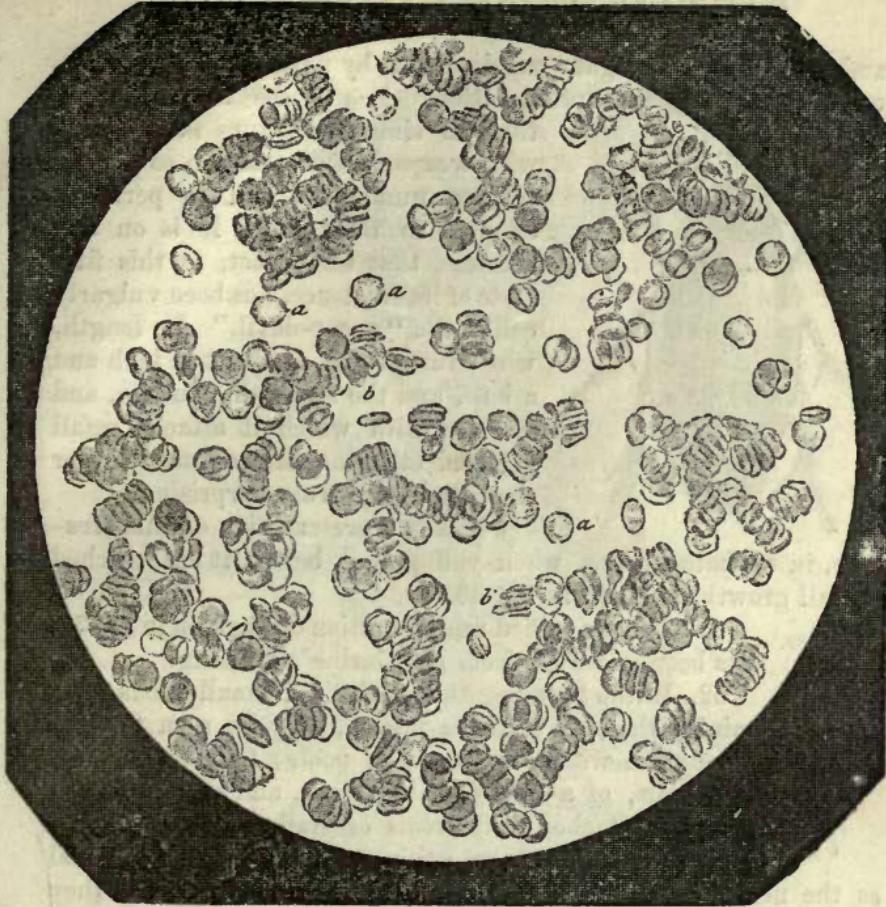


Fig. 38.—VIEW OF A THIN DISC OF HUMAN BLOOD, PRESSED BETWEEN TWO PLATES OF GLASS, THE REAL DIAMETER OF THE PART SHOWN BEING THE 120TH OF AN INCH, DAGUERREOTYPED BY MESSRS. DONNÉ AND FOCAULT.

MICROSCOPIC DRAWING & ENGRAVING.

CHAPTER III.

48. The beetle.—49. Its larva.—50. Drawing of it in its natural size.—51. Dr. Goring's magnified drawing.—52. Production of the beetle from the egg.—53. The young larva.—54. Its voracity and manner of seizing its prey.—55. Description of its organs.—56. Its chrysalis.—57. Water-beetle.—58. Gnat.—59. Dr. Goring's method of drawing.—60. Drawing by the camera-lucida.—61. Section of the human skin ; sweating-gland and duct.—62. The itch insect.—63. Method of obtaining it.

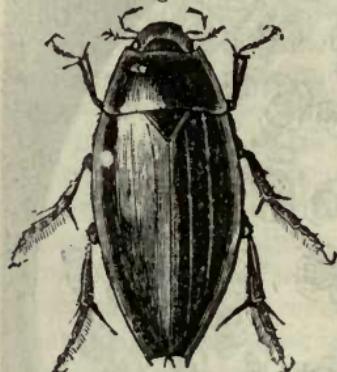
48. ANOTHER of the tribe of insects, of whose larva Dr. Goring has left a beautiful drawing, is the beetle, shown in fig. 32.

49. The larva of this insect, like the former, is an inhabitant of the water. It is remarkable for its ferocious and savage disposition,

MICROSCOPIC DRAWING AND ENGRAVING.

and for the various organs supplied to it by nature for the gratification of its ravenous propensities. It may be truly affirmed

Fig. 32



that no similar creature is provided with weapons of destruction so powerful, so numerous, and so perfectly adapted to their end; it is on this account, that the insect, in this first state of its existence, has been vulgarly called the "water-devil." Its length, when full grown, is about an inch and a half, and the strength, courage, and ferocity with which it attacks small fish and other aquatic animals larger than itself, are truly surprising.

50. The representation of this creature, in its natural size, when young, and before it has reached its full growth, is given in fig. 33.

Fig. 33. 51. The magnified representation of it given in fig. 34, has been engraved from Dr. Goring's drawing.

52. In the first months of Spring, small nests containing the eggs of these insects, may be seen floating among the weeds, in stagnant pools; they are formed like balls, of a dusky-white colour, and silky texture; they are attached to the roots or stalks of weeds at the bottom of the water by a thin stem of the same material as the nest, but stronger and more dense. Thus placed, they remain during the winter preserved from the effects of cold, even when the surface of the water is frozen over; since by a natural thermal law the temperature increases in going downwards.*

Early in spring, the stem or thread by which they are attached to the weeds, is broken by the winds, and the nest being detached and lighter, bulk for bulk, than the water, rises by its buoyancy to the surface, where being exposed to the warmth of the sun as the season advances, the eggs are hatched. The larva, however, after breaking the shell, is still confined in the bag-shaped nest; it accomplishes its liberation by gnawing a hole in it, from which escaping, it dives immediately to the bottom, eagerly devouring all the small aquatic insects that fall in its way. If, however, it should happen that there is a short supply of this food, the voracity of these creatures is such, that they fall upon and devour each other.

53. When the larva is very young, measuring not above a quarter of an inch in length, it is sufficiently translucent to enable an observer to see its internal structure with the microscope, by light

* See Tract on "Terrestrial Heat," also Handbook of Natural Philosophy, "Heat."

THE WATER DEVIL.

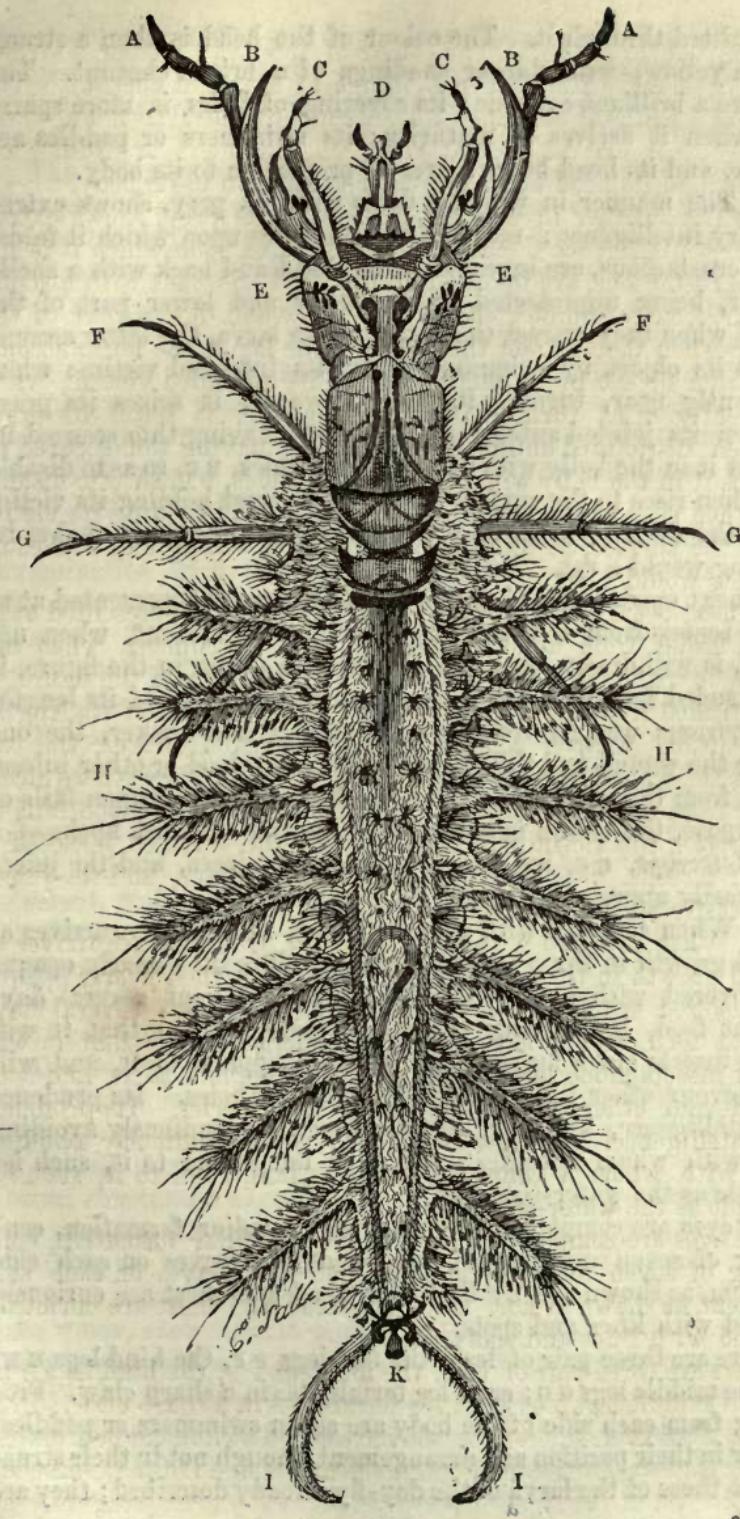


Fig. 34.—MAGNIFIED VIEW OF THE WATER-DEVIL OR LARVA OF THE BEETLE. DRAWN BY DR. GORING.

transmitted through it. The colour of the head is then a strong Indian yellow, with darker shadings of a bright chesnut. The eyes are a brilliant carmine; its covering of hairs is more sparse than when it arrives at maturity; its swimmers or paddles are shorter, and its head bears a greater proportion to its body.

54. The manner in which it deals with its prey, shows extraordinary intelligence; many of the creatures upon which it feeds, being crustaceous, are invested on the head and back with a shell-armour, being unprotected on the belly and lower part of the body; when they attract the notice of the larva, the latter accomplishes its object by swimming under its intended victim; when sufficiently near, turning its head upwards, it seizes its prey, between its jointed antennæ, A A, fig. 34; having thus secured it, it stabs it in the belly with its sharp mandibles, B B, so as to disable it, it then rises to the surface of the water, and holding its victim above the surface, so as to prevent it from struggling, shakes it, as a dog would a rat.

Its next operation is to pierce it with a weapon represented at n, which issues from a horny sheath; this instrument, when not in use, is withdrawn into the sheath. As shown in the figure, it is protruded from the sheath to about three-fourths of its length. This curious weapon consists of a piercer and sucker, the one giving the wound and the other drawing the blood or other juices. When from the nature of the part attacked, this weapon fails of its purpose, the victim is seized between the serrated hooks of a pair of forceps, c c, by which it is torn to pieces, and the juices more easily approached by the sucker, d.

55. When supplied with abundant food, this creature arrives at its full growth in three or four months, and is then nearly opaque and covered with hair. When caught and kept several days without food, its ferocity is greatly increased, so that it will attack insects much larger than itself, if supplied to it, and will even devour other individuals of its own species. Its prudence and intelligence, however, are displayed by studiously avoiding those with whom a contest would be dangerous to it, such for example as the water-scorpion.

The eyes are compound, but of a very peculiar formation, consisting of seven oval pupils, arranged like leaves on each side of a stem, as shown at E E; the entire head and chest are curiously marked with lines and spots.

There are three pair of legs, the fore legs F F, the hind legs H H, and the middle legs G G; each leg terminates in a sharp claw. Projecting from each side of the body are seven swimmers or paddles, similar in their position and arrangement, though not in their structure, to those of the larva of the day-fly already described; they are

THE WATER DEVIL.

here covered with hairs, and in the specimen from which the drawing has been made, a vast number of minute bell-shaped animalcules were attached to them, which will be recognised in the figure.

The abdomen is united to the chest or thorax a little above the first pair of swimmers, and extends to the commencement of the bifurcated tail; along the sides of the abdomen are extended the two tracheæ or air-vessels, which as already explained perform the functions of lungs; they are in this case of a light blue colour, and throw out numerous branches at various intervals in their course. These tracheæ consist of curiously formed fibres, winding round them like the twisted filaments of a rope, as may be seen in the figure. These vessels are usually distended by the air which inflates them; their diameter in a full-grown larva is about the sixteenth of an inch.

Dr. Goring states that when these membranes are submitted to examination with the microscope in the usual way, they exhibit the most beautiful specimen of line-work that it is possible to imagine. The filaments of the upper and under sides, intersecting each other at different angles, produce an effect which could not be surpassed by the finest and most beautiful engine-turning.

The orifices by which respiration is performed are at its tail, and each time that it makes an inspiration, it is obliged to ascend to the surface, above which it projects its tail, through the apertures of which it draws in air, until the entire tracheæ have been inflated; thus provided, it sinks again into its proper element, and according as the air thus inspired has changed its character by contact with the blood, and has therefore been rendered unfit for the support of life, it is expelled from the same orifices in the tail at which it entered, and may be seen rising in bubbles to the surface.

Dr. Goring observes that a comparison of the organs of respiration of this insect with those of a caterpillar, affords a beautiful example of the adaptation of their organisation to the elements in which they live. In the case of the caterpillar, every part being constantly exposed to the atmosphere, mouths or orifices for inhaling the air are arranged along both sides of the body; while in the aquatic larva, this system could not be made available without compelling the creature to elevate its entire body out of the water, each time it makes an inspiration. The necessity for this is superseded by placing the breathing-mouths in the tail.

While admitting the admirable fitness of this arrangement in the two classes of insects, it must not be forgotten, that in the case of the larva of the day-fly, also an aquatic insect, formerly mentioned, the breathing-mouths, according to Dr. Goring's

MICROSCOPIC DRAWING AND ENGRAVING.

description, are placed in the membranous paddles along its sides, and the air is imbibed from the surrounding fluid.

56. After this creature has remained for a considerable time in the state of larva, and when it appears to become conscious that the epoch of its passage into the second stage of its existence, that of chrysalis, is approaching, it issues from the water and proceeds to excavate for itself a hole in the ground, in which it undergoes the metamorphosis by which it passes into the state of a chrysalis, in which it remains for some days, after which it emerges a perfect beetle.

The female bears on each side of the hinder extremity of her body a spinning apparatus, which she uses to make the bag in which her eggs are deposited, and which has been already described.

57. Dr. Goring has also left a drawing of another species of *dytiscus*, called the *water-beetle*.

This insect resembles, in the manner of its propagation and its habits, that which has been above described. It is carnivorous, and of a ferocious and cruel character. If it is placed in a vessel with other aquatic insects, it soon devours them.

A magnified view of it is shown in fig. 35 ; the insect, in its real size, being represented in the lower figure. The drawing from which this engraving was taken, was made immediately after it had cast its first skin, a moment at which its internal organisation is more distinctly visible than at any other period of its existence, by reason of the thinness and transparency of its newly-developed vessels. Its anatomical structure is more delicate and beautiful than that of any other larva of the order of coleoptera, and, although its weapons of attack appear less formidable than those of the water-devil and some other species, the remarkable manner in which its internal functions are rendered visible more than compensate for this, when the insect is regarded merely as a microscopic object.

It is armed with a pair of curved mandibles, which move horizontally, and are long enough to cross each other when closed. They are of a fine nut colour, becoming darker towards the points, which are hard and sharp. With these the insect seizes its prey, and bringing it towards its mouth, sucks its blood after having first pierced it. This it delights to do without killing its victim, unless it is constrained to do so, by the superior strength of the latter. If it seizes the larva of the gnat, or any other tender insect, it brings different parts of its body to its mouth, devouring it piecemeal, except the skin, which it rejects. If its prey is a strong animal, protected by an external shell, it seizes it, and holds it for some time at rest, until its victim

WATER-BEETLE.

becomes completely exhausted ; or, having wounded it in several places, it turns it upon its back and sucks its juices.

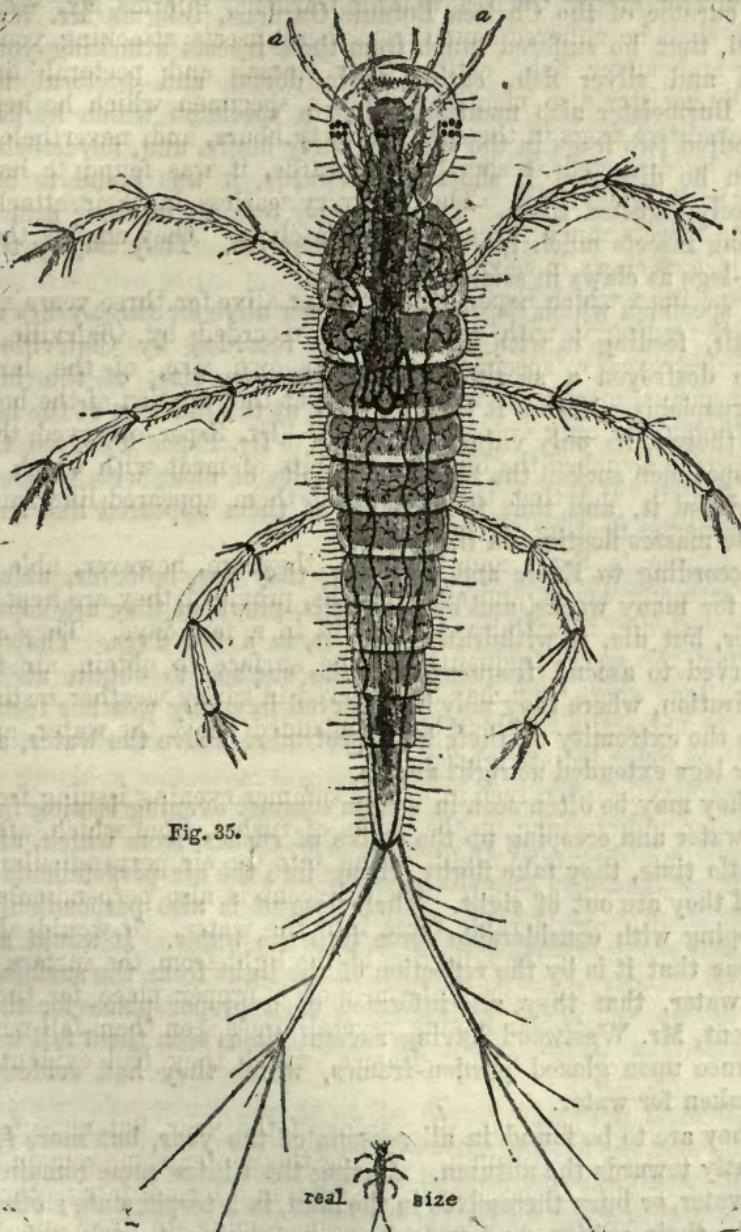


Fig. 35.

MICROSCOPIC DRAWING AND ENGRAVING.

These larvæ swim with great agility, the hind legs acting together in concert like those of a frog; the antennæ being at the same time erected, and the palpi concealed. The voracity of this creature is not directed alone to aquatic insects, but proves often very destructive to young fish in fish-ponds. Mr. Anderson, the curator of the Chelsea Botanic Gardens, informs Mr. Westwood, that he suffered much from these insects attacking young gold and silver fish, eating their dorsal and pectoral fins. Dr. Burmeister also mentions, that a specimen which he kept, devoured two frogs in the space of forty hours, and, nevertheless, when he dissected it shortly afterwards, it was found to have entirely digested them. They are very fearless in their attacks, seizing insects much larger than themselves. They employ their fore-legs as claws in seizing their prey.

A specimen which Esper kept in water alive for three years and a half, feeding it with raw beef, is recorded by Clairville to have destroyed a specimen, twice its own size, of the large *hydruspicius*, piercing it with its jaws, at the junction of the head and thorax, its only vulnerable point. Dr. Esper observed that his specimen sucked the blood of the bits of meat with which he furnished it, and that the residue of them appeared like small white masses floating on the water.

According to Esper and Erichson, they are, however, able to fast for many weeks, and even months, provided they are kept in water, but die, if withdrawn from it, in a few days. They are observed to ascend frequently to the surface to obtain air for respiration, where they may be observed in sunny weather resting with the extremity of their body protruded above the water, and their legs extended at right angles.

They may be often seen in a calm summer evening issuing from the water and creeping up the stalks of rushes, from which, after a little time, they take flight, rising into the air perpendicularly until they are out of sight. Their descent is also perpendicular, dropping with considerable force into the water. It would also appear that it is by the reflection of the light from the surface of the water, that they are informed of a proper place for their descent, Mr. Westwood having several times seen them fall with violence upon glazed garden-frames, which they had evidently mistaken for water.

They are to be found in all seasons of the year, but more frequently towards the autumn. During the winter some remain in the water, or bury themselves in the mud, in a torpid state; others retain their agility, and may be seen coming to take air in places where the ice is broken. Mr. Westwood has seen them even swimming about in the water under the ice on which he was skating.

WATER-BEETLE.

The female deposits her eggs about the beginning of spring, each laying consisting of from forty to fifty eggs of a long and cylindrical form, which are deposited in the water at random, the larvæ being hatched in the course of a fortnight.

The larva of the *dytiscus marginalis* is very active, and casts its skin, for the first time, when four or five days old. The second moulting takes place after an equal interval, and as the insect continues to grow, it casts its skin at intervals of about ten days. The hide which it throws off may often be observed floating on the water, with the mandibles, tail, and its appendages attached. These larvæ are of a dark ochre, or dirty brown colour, with the body long and subcylindric, more slender at each extremity, but especially towards the tail. The body consists of eleven segments, exclusive of the head. The first nine segments are somewhat scaly above, but fleshy beneath. The first segment is longer and narrower than the following. The sixth, seventh, and eighth, are larger than the others, which are of nearly equal size, and the two terminal joints are long and conical; the apex being slightly truncated and scaly, with the sides fringed with hairs, whereby the insect is enabled to swim along in the water, the action of these joints being the same as that of an oar used in sculling a boat.

The terminal segment of the tails is provided with a pair of long and slender pilose appendages, whereby the insect is enabled to suspend itself at the surface of the water, which, as Swammerdam says, flows from them on every side, and thus the suspension is effected. These appendages are tubular, and communicate with the air-vessels which run along the sides of the body, which is moreover furnished with a series of spiracular points, as shown in the figure. The head is large, rounded, and depressed, and united to the first segment of the body by a short neck, with five or six small elevated tubercles representing the eyes. There are two slender antennæ, shown at *a a* in the fig. 35, having a length nearly equal to the diameter of the head, inserted in front of the eyes, and composed of seven joints. The mouth is remarkably constructed, being destitute of the ordinary aperture, so that the insect may be, and, indeed, has been, described as wanting a mouth.

The mandibles, which appear in the figure projecting from the front of the head, are hollow, having a longitudinal slit near the extremity, so as to enable the creature to suck through them the juices of its prey, as a liquid is sucked through a straw or a quill, the juices thus running down the mandibles into the mouth.

The legs of the insect are long, slender, and ciliated on the inside, serving as oars when swimming quickly. The body,

MICROSCOPIC DRAWING AND ENGRAVING.

generally straight, curves itself in the shape of the letter S when the creature seizes its prey. During the summer the larva is said to attain its full size in about fifteen days, when it quits the water and creeps into the neighbouring earth, where it forms with considerable skill a round cell, in which, in about five days, it changes to a pupa of a whitish colour, with two obtuse points at the extremity of the body. In about a fortnight or three weeks it issues as a perfect beetle. If, however, the change to the pupa state take place in the autumn, the creature does not pass into the form of a perfect insect until the following spring.

The beetle is at first soft and yellowish, but soon hardens and assumes a darker colour. It is not, however, until the end of eight days, that it has acquired its proper consistency.*

Dr. Goring, in describing the specimen from which the drawing was taken, says that the three first segments of the body, commencing from the neck, contain a bundle of nerves, terminating with three loops, which are very perceptible in the young larva, being of a colour more brilliant than the other parts of the body. They are shown in the figure like a bundle of strings or cords, extending from the centre of the head to the extremity of the third joint of the body.

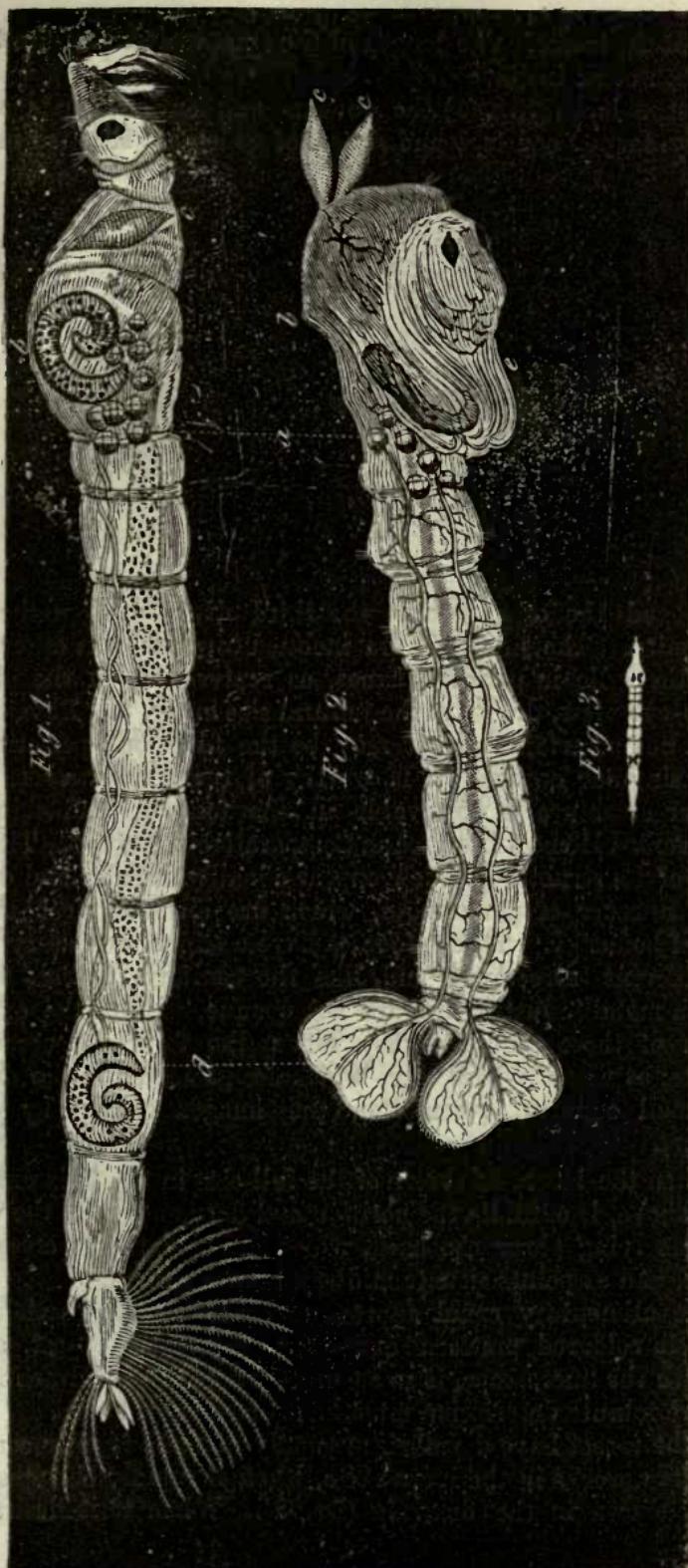
The two large tracheæ, commencing from the head, attain their greatest development about the third joint of the body. They follow the sides of the body to a point near its extremity, where they coalesce and terminate. These air-tubes, in their passage along the body, throw out numerous ramifications, which are shown in the figure. These tracheæ are four in number, two interior and two exterior. The interior ones commence at the ganglion, which terminates at the third joint of the body, and they disappear at the third joint from the tail. In the last joint but one is situated the organ of pulsation.

58. Dr. Goring has also left two very beautiful engravings of the larva and the pupa of the gnat, taken from a specimen of the species called *tipula crystallina* of De Geer, the *chironomus plumicornis* of Fabricius, and the *corethra plumicornis* of Stephens. I have reproduced these beautiful objects from Dr. Goring's engravings, the larva being represented in fig. 1, the pupa in fig. 2, and a plan, or bird's-eye view of the larva, in its natural size, in fig. 3.

The gnat, of which these are the previous forms, is represented in fig. 36, the drawing having been taken while the creature was in the act of laying the cluster of eggs figured on the right side. The short line between the figures gives the real length of the

* Westwood on "Insects," vol. i., p. 95.

STRAW-COLOURED GNAT

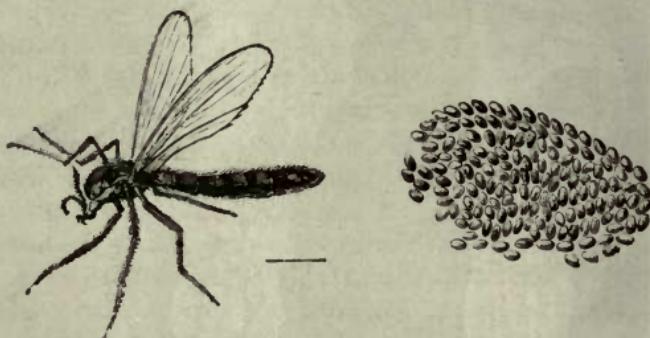


MICROSCOPIC DRAWING AND ENGRAVING.

body of the insect. The length of the eggs varies from the 40th to the 50th of an inch.

In the larva (fig. 1) the obvious and curious parts are the kidney-shaped bodies, *b* and *d*, two of which are situated near the

Fig. 36.



head, and the other two in the third division from the lower extremity. The first pair are inclined towards each other, while the others lie in parallel planes, as represented in the plan, or bird's-eye view, drawn of the natural size in fig. 3. Physiologists have not ascertained what may be the functions performed by these singular organs: it is worthy of remark, however, that a similar structure is observable in the tadpole, and figured in Sir Everard Home's Lectures on Comparative Anatomy. The other parts of its structure, which appear equally singular and curious, are a number of globules, *a*, which are situated near the first pair of bodies, *b*. These globules have a slight oscillatory motion in different directions, and, like the reniform bodies, seem to have a metallic lustre, but are not opaque. From the exquisite polish of these globules, they reflect the forms of surrounding objects, as window-bars, &c., which are indicated in the drawing by small squares, resembling the images formed by convex mirrors.

When the larva, as shown of the full size in fig. 3, is examined from above, it exhibits the position and decussation of the various muscles lying along the back, which are observed to cross at the joints, and at points situate midway between them.

The alimentary canal appears to contain some particles of a pinkish coloured matter: but every part of the object, as seen beneath the microscope, is so accurately noted in the drawing, that a more minute description must be deemed superfluous.

If the insect have a sufficient supply of food, it only continues for a few weeks in the larva state, when it rapidly changes to the pupa, shown in the drawing (fig. 2). When it is desirable to

STRAW-COLOURED GNAT.

preserve it for the microscope, this change may be retarded by keeping it in clear spring or river water. The former seldom offers sustenance to animalcules, and, therefore, effects this object, which is often very desirable, on account of the scarcity of this species.

The transformation of this animal from the larva to the pupa is one of the most singular and wonderful changes that can be conceived; and, under the microscope, presents to the admirer of nature a most curious and interesting spectacle. Although the whole operation be under the immediate inspection of the observer, yet so complete is the change, that its former organisation can scarcely be recognised in its new state of existence.

If we now compare the different parts of the larva with the pupa, we remark a very striking change in the tail, which, in the previous state of being, was composed of twenty-two beautifully plumed branches, while, in the latter, it is converted into two fine membranous tissues, ramified with numerous vessels. This change appears the more remarkable, as not the slightest resemblance can be discovered between them, nor are the vestiges of the former tail readily found in the water. The partial disappearance of the shell-like or reniform bodies is another curious circumstance. The lower two, it may be conjectured, go to form the new tail; for, if the number of joints be counted from the head, the new tail will be found appended to that joint which was nearest to them in the larva state, as referred to by the dotted line *d*, connecting figs. 1 and 2. The two small horns, *c c*, which form the white-plumed antennæ of this species of gnat, when in its perfect state, are discernible in the larva, folded up under the skin near the head at *c*, in fig. 1. The alimentary canal appears nearly to vanish in the pupa, as in that state there is no necessity for it, the insect then entirely abstaining from food; while, near this canal, the two intertwined vessels, seen in the larva, have now become more distinct, and are supplied with several anastomosing branches.

During the latter part of the day on which the drawing (fig. 2) was taken, the rudiments of the legs of the perfect insect might be seen, folded within that part which appears to be the head of the pupa, and several of the globules had vanished, those remaining longest that were situated near the head. It may be necessary to observe, that the head of the pupa floats just under the surface of the water; and the insect, in this state, is nearly upright in that fluid, while the larva swims with its body in a horizontal position, or rests on its belly or sides, at the bottom of the pond or vessel in which it is kept, the fringed tail being downwards.

The colour of the larva when young is a faint and scarcely perceptible yellow; but as it approaches the change, it assumes a

MICROSCOPIC DRAWING AND ENGRAVING.

richer and deeper colouring, and all its internal parts acquire their definite forms and tints, as exhibited in the drawing.

A curious circumstance attends the observation of this insect; so rapid is its locomotion, that it torments the eye while attempting to delineate it, presenting alternately its head and tail to the observer. This it effects by bending itself laterally into a circular form, and suddenly whisking round in the opposite direction to that in which it had just bent itself.

Many species of this genus of insects are, in their perfect state, possessed of a sheathed proboscis, containing instruments with which they are enabled to pierce the skin of men and cattle, injecting at the same time an acrimonious fluid into the wound. The species we are now describing, however, has not been examined minutely enough to determine the form of these organs. It is of a light straw colour, and has two beautiful antennæ, or feelers.

The wings also of this gnat are of a delicate straw colour, and make very beautiful objects when mounted under thin glass in sliders. Some species have wings marginated, and covered with fine scales. These, as well as the feathers on the edges, are good objects for the microscope, and exhibit five or six longitudinal lines on each, which are so strongly marked as to be seen with any kind of light, and do not require superior penetration in the instrument to show them.

These insects generate while hovering in the air, and the female lays her eggs in the water, selecting an unfrequented spot, where she may deposit them free from danger. This is probably the cause why this larva is discovered with so much difficulty; the collector being seldom able to procure it two seasons consecutively in the same place.

59. The method of executing these drawings, practised by Dr. Goring, differed in nothing from that by which an artist makes a portrait, the eye guiding the pencil, and the accuracy of the resemblance depending altogether upon the skill of the artist.

60. Dr. Goring considered that in such cases the great security for precision offered by the camera-lucida, was not available, owing to the constant mobility of the object delineated; this objection, however, is only applicable to living objects, and that admirable instrument is accordingly used to a great extent in the production of microscopic drawings. As we shall describe it in a future Tract, and explain its mode of application to the microscope, it will not be necessary here to give that exposition. It will be sufficient to observe that a practised draughtsman is capable of giving, not only the general outline, but most of the less minute details of a microscopic object, by a

THE ITCH INSECT.

process precisely similar to, and susceptible of, as much accuracy as that by which a drawing is reproduced on tracing paper. It must be observed, however, that in the finishing touches, and the most minute details, the pencil of the draughtsman must after all be guided by his artistic skill. To what extent this is true, is proved by the fact, that two drawings of the same object, viewed in the same microscope, and made with the same camera, by artists of different skill, will be different.

We shall here, as in the former case, present the reader with some examples of microscopic drawings made by the aid of the camera.

61. In fig. 41 is a magnified section of the human skin, cut inwards at right angles to its surface, to the depth of about the sixth of an inch. The following is the succession of organised parts included within that depth:—*a* the sudoriferous gland; *b c* the sudoriferous duct, leading to the surface of the skin; *d* the subcutaneous cellular and adipose tissue; *e* the derma or true skin; *f* the papillæ; *g* mucous tissue or interior epidermis; *h* the epidermis or superficial skin.

62. It is now admitted, though the fact was long doubted, that the malady called the itch in the human body, and that called the mange in the horse, are produced by an insect hatched under the cuticle of the skin; the insect which produces the itch, called the *acarus-scabiei*, is represented, highly magnified, in fig. 42. To extract this insect, the operator must, says Mr. Quekett, examine carefully the parts surrounding each pustule, and he will generally find, in the early stage of the disease, a red spot or line communicating with it; this part, and not the pustule, must be probed with a pointed instrument, and the insect, if present, turned out of its lurking-place. The operator must not be disappointed by repeated failures, as in the best marked cases, it is often difficult to detect the haunts of the creature.

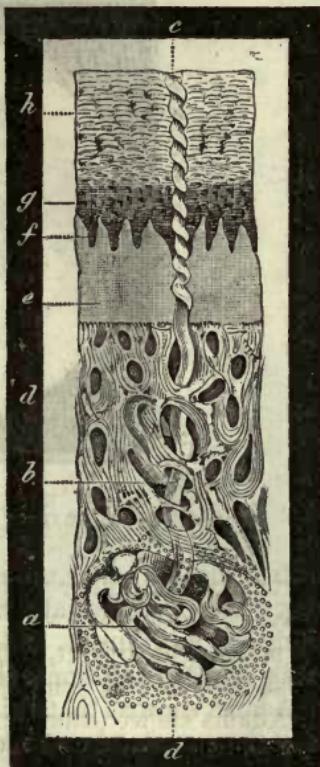


FIG. 41.—MAGNIFIED SECTION OF THE HUMAN SKIN, SHOWING THE PERSPIRATORY GLAND, WITH ITS DUCT, DRAWN WITH A CAMERA BY DR. MANDL.

63. That the itch is occasioned by such an insect is by no means a modern doctrine. Kirby mentions a Moorish physician, who, in the twelfth century, affirmed that the malady was produced by little mites or lice that creep under the skin of the hands, legs, and feet, producing pustules full of matter; he quotes also "Joubert," another ancient physician, who describes

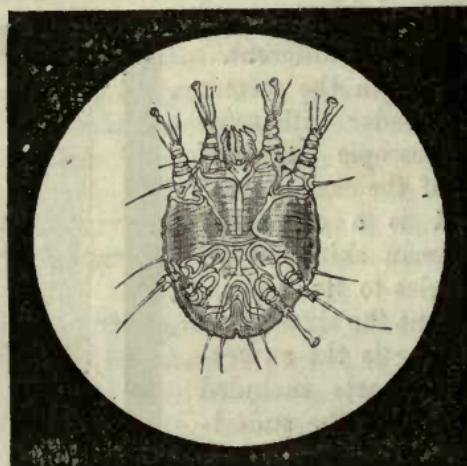


Fig. 42.—VIEW OF THE ITCH INSECT, DRAWN WITH A CAMERA BY DR. MANDL, MAGNIFIED 120 TIMES IN ITS LINEAR, AND THEREFORE 14400 TIMES IN ITS SUPERFICIAL DIMENSIONS.

the itch insects under the name of "sirones," and says they are always concealed beneath the epidermis, under which they creep like moles, gnawing it, and producing a most troublesome itching. It was supposed by some that they were identical with lice; but Dr. Adams showed that this could not be the case, since they live under the cuticle; he speaks of them as living in burrows which they have excavated in the skin, near a lake of water, from which if they be extracted with a needle, and put upon the nail, they show in the sun their red heads and the feet with which they walk; they have been extracted and delineated with the aid of the microscope by many modern observers. The individual delineated in fig. 42, was drawn by my friend Dr. Mandl, well known for his great work on microscopic anatomy.

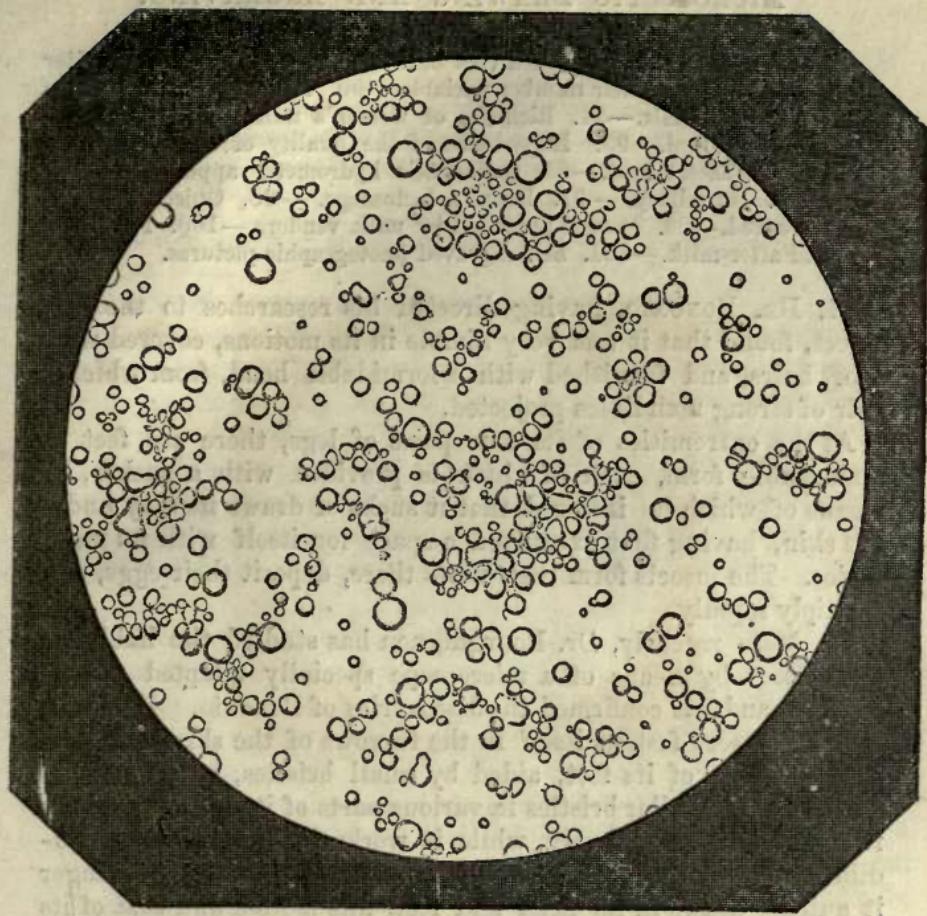


Fig. 40.—THIN DISC OF COW'S MILK, THE 120TH OF AN INCH IN DIAMETER, MAGNIFIED 400 TIMES IN ITS LINEAR, AND 160000 TIMES IN ITS SUPERFICIAL DIMENSIONS.

MICROSCOPIC DRAWING & ENGRAVING.

CHAPTER IV.

64. Structure of the itch insect.—65. Its habits.—66. The mange insect.—67. Its form and structure.—68. Defects incidental to drawing with the camera.—69. Microscopic photographs.—70. Microscopic daguerreotypes by Messrs. Donné and Foucault.—71. Description of the blood.—72. Red and white corpuscles.—73. Daguerreotype of a drop of blood magnified.—74. Magnitude of the corpuscles.—75. Cause of the redness of blood.—76. Corpuscles of inferior animals.—77. White globules.—78. White grains.—79. White globules converted into red corpuscles.—80. Red corpuscles dissolved.—81. Circulation of the blood.—82. Method of showing it in the tongue of a frog.—83. The arteries distinguishable from the veins.—84. The vascular system of the tongue.—85. Mucous glands.—86. Milk; its

MICROSCOPIC DRAWING AND ENGRAVING.

constitution.—87. Magnified view of a drop of milk.—88. The butter globules.—89. Their number variable.—90. Analysis of the milk of different animals.—91. Richness of woman's milk.—92. Analogy of milk to blood.—93. Importance of the quality of milk.—94. Its richness ascertained.—95. Quévenne's hydrometer applied to milk.—96. Its fallacy.—97. Donné's lactoscope.—98. Objections to it answered.—99. Frauds practised by milk vendors.—100. Fore-milk and after-milk.—101. Self-engraved photographic pictures.

64. DR. BONONIO, having directed his researches to the itch insect, found that it was very nimble in its motions, covered with short hairs, and furnished with a formidable head, from which a pair of strong mandibles projected.

At the extremities of its four pairs of legs, there are feet of remarkable form, each of which is provided with a sucker, by means of which he inferred that it sucks or draws its way under the skin, having first excavated a space for itself with its mandibles. The insects form their nests there, deposit their eggs, and multiply rapidly.

65. More recently, Dr. Bourguignon has studied the habits of this insect by means of a microscope specially adapted to the purpose, and has confirmed the discoveries of Bononio. He found that the insect fastens itself in the furrows of the skin by means of the suckers of its feet, aided by small bristles, being likewise covered with similar bristles in various parts of its body, by which it fixes itself more firmly, while it works its way with its mandibles; it is not furnished with eyes, but in a moment of danger it quickly draws in its head and feet, this motion and that of its gait resembling those of a tortoise. It usually lays sixteen eggs, which it deposits, ranged in pairs, in the furrows under the skin, where they are hatched in about ten days.*

66. The insect which produces or accompanies the mange in horses, and which is called the *acarus-exulcerans*, is represented in fig. 37, p. 49, magnified in its linear dimensions one hundred and fifty times.

67. This animalcule is larger and more easily obtained than the former; it is found under the whitish scales which are detached from the skin of the horse, and if several individuals be taken, they will be found to be in different states of development, having four pair of legs when full grown; the two foremost pairs are terminated in a strong and sharp claw, and their general form is like that of the legs of a flea, consisting of five joints or segments.

The head consists of nothing but a mouth, in which the organs of mastication are seen, consisting of a pair of very fine and sharp

* Bourguignon, quoted by "Hogg" on the Microscope, p. 318.

MICROSCOPIC DAGUERREOTYPES.

mandibles terminated by two teeth, the form of the entire organ being that of a pincers. The skin, which is of a tough leathery texture, is elegantly marked by sinuous and parallel tracings, bearing some resemblance to engine-turning. Wrinkles are in some places seen upon it, as if it were divided into separate segments, united edge to edge, like the bones composing the human skull ; upon the legs, the skin is finely granulated and not striated, as upon the body ; several long hairs issuing from the legs are seen in the figure.

68. Although the general fidelity of microscopic drawings made with a camera may be relied upon, yet, as has been already observed, the more minute details are executed by the artist in the same manner as that in which a portrait-painter produces his effects, and in whatever degree the artistic skill of the draughtsman may be manifested in such parts of the drawing, the rigorous fidelity demanded by science, even in the minutest arts, cannot be claimed for them.

69. Under these circumstances, other means, ensuring more rigorous accuracy, and rendering the drawing independent altogether of those impulses which imagination and taste never fail to impart to the pencil even of the most conscientious artist, have been eagerly sought by naturalists, and have been happily supplied by photography. The magnified image of the object under examination, produced by a solar microscope, is received upon a prepared daguerreotype-plate, or a leaf of photographic paper, and there the optical image delineates itself with the most unerring fidelity and rigorous accuracy.

70. This felicitous application of the photographic art, to the promotion of natural science, after some experimental essays, more or less successful, was first carried out, so as to be available for the practical purposes of science, by Dr. Donné, assisted by M. Leon Foucault, in 1845. In that year Dr. Donné published an atlas to illustrate his course on microscopic anatomy and physiology, which had appeared in the previous year, consisting of twenty plates, on each of which were four microscopic engravings, made from daguerreotype plates which had been produced in the manner above described. I avail myself gladly of the kind permission of the authors of this work, and of Mr. Bailliére, its publisher, to reproduce four of these engravings upon the scale on which they are given by the authors.

71. The blood of animals is not, as it seems at first view to be, a homogeneous liquid holding in complete solution certain substances, and destitute of all solid and concrete matter ; if it were so, we could not follow its course through the vessels in which it moves, as we do so easily and distinctly with the microscope.

The motion of an homogeneous liquid in tubes completely filled with it could not be made sensible to the sight ; but on the other hand, that of a liquid containing solid particles suspended in it, continually entering into collision with and displacing each other, would be perfectly visible.

The blood therefore contains certain solid particles floating in and circulating with it, to which moreover are due several of its most important properties ; these particles exist in countless numbers, and of minuteness so extreme, that a single drop of blood, no larger than might be suspended from the point of a needle, contains myriads of them. Until recently, observers recognised only one species of the corpuscles, such being the only ones perceptible by the ordinary methods of observation, and being incomparably more numerous than the others, which, besides being more rare, are generally hidden by the former, which completely fill the field of the microscope.

72. These sanguineous corpuscles are distinguished by regular and constant forms, by a complex composition and a determinate structure. They possess a real organisation, and pass through a regular succession of phases, having a beginning, a development, and an end.

They consist of three species : first, red corpuscles ; secondly, white globules ; and thirdly, white granular particles, much smaller, to which observers have applied the name "globulines."

73. Nothing can be more simple or more facile than the method of observing the first class of these corpuscles. Take a sharp needle and prick with it slightly the end of the finger, so as to draw the smallest drop of blood ; having previously rendered a small slip of glass perfectly clean and dry, touch it with the blood, a small portion of which will adhere to it, and upon this lay a thin film of glass, such as are prepared by the opticians for microscopic use, so as to flatten between the two glasses the small drop of blood. Let the glass thus carrying the blood be placed under a microscope having a magnifying power of about 400 ; a multitude of the red corpuscles will then be immediately visible, distributed irregularly over the field of view of the instrument.

Fig. 38, p. 81, has been reproduced from one of Dr. Donné's engravings ; it represents a thin disc of human blood, having a diameter equal to the 120th part of an English inch, included between the two glasses.

The red corpuscles alone are here visible ; their form is that of flat discs a little concave in the middle, swelling upwards towards the edges, which are slightly rounded. Some of them, such as *a a a*, are presented with their flat sides to the line of sight, so as to show very distinctly their form ; others, such as *b b*, are

DROP OF BLOOD.

seen edgeways, and others at all degrees of obliquity; some are scattered separately, but others are grouped together in piles, with their edges presented to the eye, having the appearance of rouleaux of coin lying on their sides on a table, the faces of the coins being more or less inclined to the surface of the table.

The flat disc-shape form of the corpuscles was not recognised by the earlier observers, who took them to be red spherules. The cause of this error was not any defect of their observation, but arose from their having previously washed the blood with water, being ignorant that the immediate effect of the contact of water with human blood is to change the form of the flat corpuscles into that of little globes.

74. The magnitude of these corpuscles, since the recent improvements of the microscope, has been very exactly measured. Their diameters are found to vary from the 3125th to the 3000th of an inch: this small variation being due to their different states of development, as will be presently explained.

75. The blood consists of a transparent, limpid, and colourless fluid, in which the solid particles already mentioned float, and the redness of which arises altogether from the colour of the corpuscles here described. A person, who may observe for the first time these corpuscles with the microscope, is generally surprised and disappointed to find that they are not red, but rather of a yellowish colour, having a very faint reddish tint. This circumstance, however, is an optical effect of a very general class, which has been explained more than once in our Tracts. When any coloured medium is submitted to the eye, the depth of its tint will always be diminished with the thickness of the medium, which may be reduced to such a degree of tenuity as to render its peculiar colour altogether imperceptible. We mentioned formerly, as an example of this, the case of coloured wine, such as sherry, viewed through a tapering Champagne glass. At the upper part, where the eye looks through a greater thickness of the liquid, the peculiar gold colour is strongly pronounced; but in going downwards to the point of the cone, the colour becomes paler and paler, and at the very point is scarcely perceptible. It is the same with the red corpuscles of the blood. When they are seen singly through their very minute thickness, they appear of the faintest reddish yellow; seen in rouleaux edgeways, they are redder; but it is only when amassed together, in a stratum of blood of some thickness, that they impart to the liquid the red colour so characteristic of the blood.

76. The disc-shaped form which thus characterises human blood, is common to all species of animals which suckle their young, with the single exception, so far as is known at present,

MICROSCOPIC DRAWING AND ENGRAVING.

of the camel species. It appears, from some recent observations of Dr. Mandl, that the blood of this species presents an anomalous exception, the red corpuscles being elliptical in their form, but still flat and concave at their sides.

In comparing the red corpuscles of the blood of different species of mammalia, or suckling animals, one with another, they are found to vary in their diameters, being greater or less in different species, but the variation in each species being confined within narrow limits, as in man.

The corpuscles of the blood of birds, fishes, and reptiles, are all like those of the exceptional case of the camel, oval discs of various magnitudes, somewhat concave in their centres, like the blood of mammalia.

77. The discovery of the white globules is entirely due to recent observers, and particularly to Professor Müller, Dr. Mandl, and Dr. Donné.

The white globules have nothing in common with the red corpuscles, either as to colour, form, or composition. Unlike the latter, they are spherical, their contour is slightly fringed, and not well defined like that of the red corpuscles; their surface is granulated, and their diameter is a little greater, varying from the 2500th to the 3000th of an inch. They appear to consist of a thin vesicle, or envelope, the interior of which is filled with solid granulated matter, consisting usually of three or four grains, while the red corpuscles are filled with an homogeneous and semi-fluid matter in the case of mammalia, and a single solid kernel in the case of other vertebrated animals.

The white globules also have chemical properties totally different from those of the red corpuscles.

78. In fine, the third class of solid particles which float in the blood cannot be properly denominated globules, being only very minute granulations, which are continually supplied by the chyle to the sanguineous fluid; they appear in the microscope as minute roundish grains, isolated, or irregularly agglomerated, and having a diameter not exceeding the 8000th of an inch: they have, however, a physiological importance of the first order, since they are the primary elements of the blood, and therefore of all the other organised parts of the body.

79. It appears to follow from the observations, researches, experiments, and reasoning of Dr. Donné, that these granular particles form themselves into the white globules by grouping themselves together, and investing themselves with an albuminous envelope. By a subsequent process, the white globules are converted gradually into the red corpuscles, the place where this change is produced being supposed by Dr. Donné to be the spleen.

CIRCULATION OF THE BLOOD.

80. In fine, the red corpuscles, after having been fully developed in the circulation, are dissolved, and being converted into the fibrinous fluid, pass into the other parts of the organisation, so as to form the different organs of the system.

81. Next to the constitution of the blood, no subject connected with it is more interesting and important than its circulation, and we know no spectacle presented by any of the scientific artifices, by which the secret operations of nature are disclosed to our view, which excites more astonishment and admiration than the circulation of the blood, as rendered visible with the microscope.

82. Let any one imagine an animal organ, full of every variety of blood-vessels of the most complex structure, into the composition of which enter every form of organ: arteries, veins, capillaries, muscles, nerves, glands, and membranes: representing in short a microcosm of the whole animal organisation; and let us suppose this brought within the field of the microscope, so as to display, before the wondering view of the observer, all the complicated motions and operations of which it is the theatre. Such a spectacle is presented by the tongue of the frog, an object first submitted to this species of experiment by Dr. Donné, at the suggestion of a young Englishman, a Mr., since Dr., Waller, who was in attendance upon his course. The method of accomplishing this, with some modifications, as described in the *Physiological Journal*, is as follows:—"A piece of cork, from two to three inches in breadth, and six to eight inches in length, is to be procured, in which is to be bored, a hole of about half an inch in diameter midway between the sides, and about an inch and a half to two inches from one of its ends. In this part the piece of cork should be of double thickness, which is effected by joining, by means of marine glue, a small piece of cork upon the first piece. Upon this is laid the frog, previously enveloped in a linen band, or fixed to the cork by pins thrust through the four extremities, so as to prevent any great movements of its body or its feet; it is placed upon the back, the end of the nose abutting on the border of the hole. The tongue, the free end of which is directed backwards, is then to be drawn out of the mouth gently with a forceps, and slightly stretched and elongated until it reaches a little beyond the opposite edge of the hole, where it is to be fastened by two pins; the sides are to be fastened over the hole in a similar way. In this state, the tongue presents the appearance of a semi-transparent membrane, which permits us to see through its substance; and when placed between the light and the object-glass of the microscope, offers one of the most beautiful and marvellous spectacles which can possibly be witnessed. It will be found most

convenient to view it, first, with a simple magnifying-glass, having a power of 15 to 20, so as to obtain a general view of the vessels and of the circulation; even with this small power the observer will be filled with astonishment at the magnificence of the spectacle, especially if a strong light is thrown upon the lower side of the tongue. To imagine a geographical map to become suddenly animated, by their proper motions being imparted to all the rivers delineated upon it, with their tributaries and affluents, from their fountains to their embouchures, would afford a most imperfect idea of this object, in which is rendered plainly visible, not only the motion of the blood through the great arterial trunks, and thence through all their branches and ramifications to the capillaries, but also its complicated vorticicular motions in the glands, its return through the smaller ramifications of the veins to the larger trunk veins, and its departure thence *en route* for the heart. Such is the astonishing spectacle, circumscribed within a circle having the diameter of the 120th of an inch, magnified, however, 400 times in its linear, and therefore 160000 times in its superficial dimensions, which has been daguerreotyped by Messrs. Donné and Foucault, and which is reproduced on the same scale in fig. 39, p. 65.

83. The arteries are distinguishable from the veins very readily, by observing the direction in which the blood flows, its velocity, and their comparative calibre. In the arteries the blood flows from the trunk to the branches, its course is marked by the arrows in fig. 39, where *t* is a trunk-artery entering near the lowest point of the field of view; the arrows show the course of the blood passing into the principal branches, 1, 2, and 3, from which it flows into all the smaller arterial ramifications. The course of the blood in the veins, on the contrary, is from the branches to the trunk, from whence it finds its way back to the heart. The arteries, moreover, are of less calibre than the veins, and consequently the blood flows in them with greater velocity. The greater arteries are accompanied by a greyish flexible cord, which can be perceived, but not without some attention; it passes along the sides of the artery: this cord is only a nerve.

As the ramifications of the arteries are multiplied they are diminished in calibre, and merge at length in the capillaries, from which they are scarcely distinguishable, the latter being equally indistinguishable from the smaller veins. As these conduits of the blood diminish in diameter, the red corpuscles at length so completely fill them, that they can only move in them one by one, and they can be thus seen following one another at perceptible intervals. If the microscope be directed to that part of the edge of the tongue, which is within the limits of the hole made in the

MICROSCOPIC VIEW OF MILK.

cork, the blood can be traced in its course to the extreme arteries, and thence from the smaller to the larger veins on its return to the heart.

84. The vascular system of the tongue appears traced upon a greyish semi-transparent brown, on which a multitude of fine fibres, *v v*, are seen extended in different directions; these existing at different depths within the thickness of the tongue, appear superposed and interlaced; these fibres belong to the muscle of the organ, and their characteristic action is rendered evident in the microscope, by their alternate contraction and extension. A number of greyish spots, somewhat round in their outline and a little more opaque than the neighbouring parts, appear scattered through the tongue; these spots belong to the mucous-membrane, and are in fact parts of the glands in which saliva is secreted. They are the theatres of a surprisingly complicated and active blood-motion. The sanguine fluid enters them at one side, generally by a single small artery, rarely by two, and following the course of this artery, it pursues a nodulated path, resembling the form of a bow of ribbon, or the figure 8, and issues from them at a point opposite to that it entered. The organ of which we speak, says Dr. Donné, having a certain thickness, we cannot always see at once the entrance and departure of the blood, the point of its departure being often in a plane inferior or superior to that of its entrance, and the two points not being, therefore, at the same time in focus. But in any case, nothing can be more curious or more profoundly interesting than the vortices of rapid circulation, thus exhibited, in a space so circumscribed and within the limits of an organ, which is evidently one of secretion.

85. These greyish spots in short, in which the circulation proves to be so active, are nothing but the mucous-follicles of the tongue, the little glands in which is secreted the viscous humour which coats in such abundance the tongue of the frog, and we accordingly find that if it be wiped off, it will be almost immediately reproduced.

86. The milk of mammalia being the first nourishment taken by their young, and their only nourishment until a certain epoch of their growth, it might naturally be expected that that fluid would have a close analogy to the blood. The examination of milk accordingly, whether with the microscope or by means of chemical analysis, proves such an anticipation to be well-founded. If a small drop of milk be laid upon a clean slip of glass, and covered by a thin film of glass, so that a thin stratum of the fluid shall be included between them, it is found on submitting it to the microscope, in the same manner as has already been described

MICROSCOPIC DRAWING AND ENGRAVING.

in the case of the blood, that very similar appearances are presented. A multitude of minute pearly spherules with the most perfect outline, reflecting light brilliantly from their centre and varying in magnitude from the 12500th to the 3000th part of an inch in diameter, and even larger still, are seen floating in the fluid.

The general magnitude and number of these globules vary much, not only in the case of one species of animal compared with another, but with different individuals of the same species, and even with the same individual under different circumstances.

87. In fig. 40, p. 97, we have given the appearance presented by a thin disc, the 120th of an inch in diameter, of common cow's milk magnified 400 times in its linear, and therefore 160000 times in its superficial dimensions, engraved from a daguerreotype by MM. Donné and Foucault.

88. It appears from the researches of physiologists on this subject that the pearl-like globules, which thus float in such multitudes in milk are the constituents out of which butter is formed. The serous fluid in which they float is composed of the constituent out of which cheese is formed, combined with another substance called sugar-of-milk, and water, the last constituting from 80 to 90 per cent. of the whole, so that, in fine, milk in general may be regarded as water holding in solution the substances called sugar-of-milk and caseine, the name given to the cheesy principle, with the globules of butter already described floating in it.

89. The proportion in which these constituents enter into the composition of milk varies, the richness always depending on the proportion of globules of butter contained in it.

90. The following is an analysis of the milk of the woman, the cow, the goat, and the ass, according to Meggenhofen, Van-Stiptrian, Liuscius, Bonpt, and Pélidot:—

	Woman.	Cow.	Goat.	Ass.
Butter	8·97	2·68	4·56	1·29
Sugar of Milk	1·20	5·68	9·12	6·29
Cheesy matter	1·93	8·95	4·38	1·95
Water	87·90	82·69	81·94	90·47
	100·00	100·00	100·00	100·00

91. From this and similar analyses it appears that woman's milk is by far the richest of the mammalia, containing generally little short of 10 per cent. of butter, while the milk of other species contains no more than from 1 to 4 per cent. of that principle.

It must, however, be observed that these are average proportions,

CONSTITUTION OF MILK.

and that the richness of the milk differs considerably in different individuals. It is found that in all cases the milk is sufficiently rich in the cheesy principle, the constituent in which it fails being the butter, which is the most important in respect to nutriment.

The butter globules of woman's milk, though much greater in quantity, as appears above, than those in the milk of inferior animals, appear from the observations of Dr. Donné to be smaller in magnitude. We have given in fig. 43, the appearance

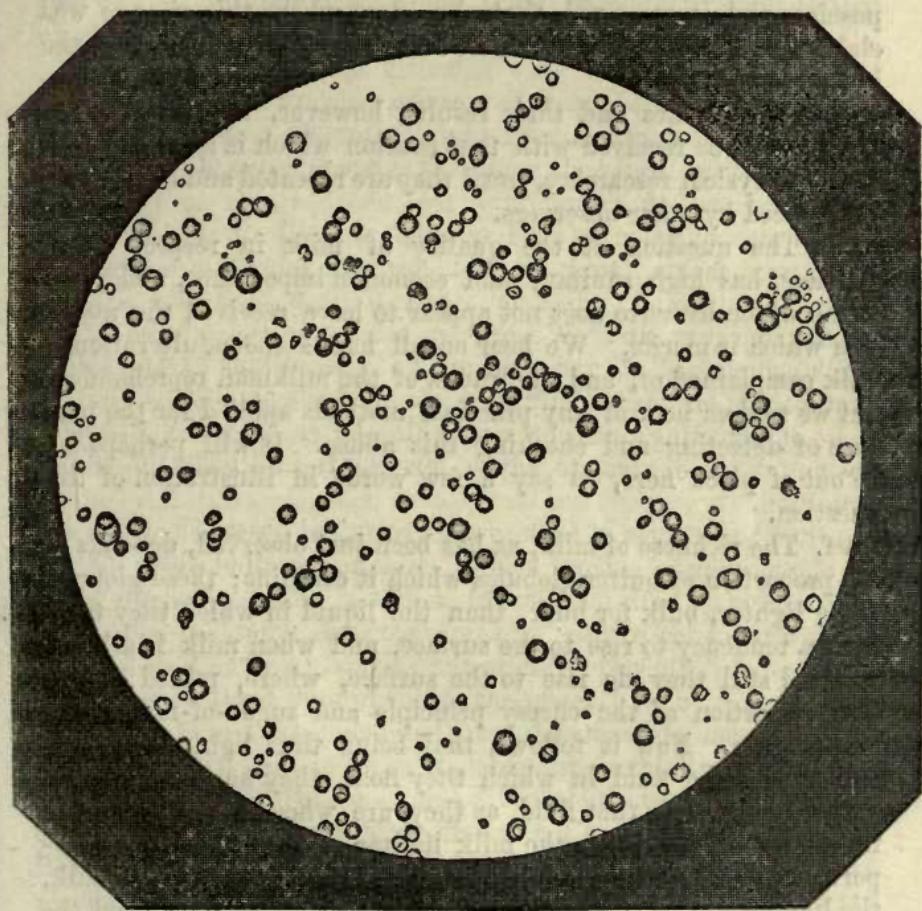


Fig. 43.—THIN DISC OF WOMAN'S MILK, THE 120TH OF AN INCH IN DIAMETER, MAGNIFIED 400 TIMES IN ITS LINEAR, AND 160000 TIMES IN ITS SUPERFICIAL DIMENSIONS.

of a disc of ordinary woman's milk, magnified similarly to fig. 40. The difference between the magnitude of the globules is apparent.

92. The analogy of milk to blood manifested in a manner so striking by the microscope, was still farther investigated in a series of highly interesting experiments made by Dr. Donné.

That eminent physiologist transfused milk into the blood vessels of various animals, with all the precautions necessary to prevent the admission of air. It was found generally that the vital functions of the animal, were neither interrupted nor disturbed; the milk mingled with the blood and circulated with it through the system, its presence being detected in all the vessels. But the most interesting and important result of these researches, was, that the butter globules of the milk were found to assimilate themselves to, and play the same part with, the white globules of the blood, and like them were gradually converted into red corpuscles, and it appeared that the place where this change was elaborated was, as in the case of the white corpuscles of the blood, the spleen.

These researches and their results, however, being recent and novel, must be received with that caution which is always necessary in physical researches, until they are repeated and like results reproduced by other observers.

93. The question of the quality of milk in respect to its richness, has high sanitary and economic importance, and yet it is one which hitherto does not appear to have received the attention which it merits. We hear on all hands the adulteration of milk complained of, and the frauds of the milkman reprehended; but we seldom hear of any practical methods applied for the purpose of detecting and checking this abuse. It will perhaps not be out of place here, to say a few words in illustration of this question.

94. The richness of milk, as has been just observed, depends on the proportion of butter globules which it contains; these globules being lighter, bulk for bulk, than the liquid in which they float, have a tendency to rise to the surface, and when milk is allowed to stand still they do rise to the surface, where, mixed with a certain portion of the cheesy principle and sugar-of-milk, they form cream. Now it follows, that being thus lighter, bulk for bulk, than the fluid in which they float, they have a tendency, when mixed with that fluid, as they are when the milk is in its natural state, to render the milk lighter, and the larger the proportion is in which these butter globules are mixed with the milk, the lighter will be the milk. It was therefore inferred, that the lightness of the milk might be taken as a test of its richness, and M. Quévenne invented a species of hydrometer, which he proposed to apply to test the richness of milk, in the same manner as the ordinary hydrometer is applied to test the strength of spirits. But the indications of this instrument, ingenious as it is, are fallacious.

95. Let us suppose that the fraudulent milkman allowing the

milk he proposes to sell, to stand until the richer portion forms a creamy stratum at its surface, then skims off this stratum which he sells at a high price, as cream. The remainder and impoverished portion of the milk is then undoubtedly heavier than before it was deprived of the cream, and its poverty would be detected by Quévenne's hydrometer: but the crafty milkman, aware of this, has the adroitness, not only to correct the too great weight of the fluid, but to do so to his own increased profit. He knows that the addition of water will diminish the specific gravity of his skimmed milk, and he accordingly mixes with it just so much of that cheap liquid as will reduce its weight to that of milk of the proper richness.

96. This manœuvre is attended also with another deceptive effect; it is found that the mixture of water with milk facilitates the disengagement of cream, and expedites its collection at the surface. Whatever creamy particles, therefore, may remain in the milk thus impoverished and adulterated, will rise quickly to the surface, and collecting there, will deceive the consumer, producing the impression that the milk on which cream so quickly collects, must necessarily be rich.

The great importance of discovering such an easy and practicable test of the quality of an element so important to the sanitary condition of the people, as milk, ought, one should have supposed, to stimulate scientific men to such an invention. The frauds practised so extensively by the vendors of milk on great public establishments, such as hospitals and schools, are notorious. An eminent medical practitioner says, that in conversing with one of the great milk contractors of the public establishments in Paris, during a season in which forage had risen to a very high price, the milkman observed frankly, and with a smile, "in common seasons, we do put a little water to the milk, but at present we are obliged to put milk to the water."

97. Dr. Donné has invented an instrument to ascertain the richness of milk, which he calls a *lactoscope*, which was presented to the Academy of Sciences, and favourably reported upon by a committee consisting of MM. Thénard, Chevreul, Boussingault, Regnault et Séguier, who experimented with it and verified its results. This instrument is based upon the fact, that while the butter globules, which float in milk, are opaque, the liquid which surrounds them is nearly transparent. It follows from this, that the transparency of milk will diminish as its richness increases, and *vice versa*.

The lactoscope consists of two plates of glass, set parallel to each other, so as to form a cell in the end of a tube, like an opera-glass, the cell being at the wide end of the tube. A screw-

adjustment is provided, by which the distance between the plates of glass may be varied within certain limits, so that by turning the screw in one way, the plates may be brought into absolute contact, and by turning it the other way, they may be separated by any desired interval. Over this cell, is provided a small cup, with a hole in its bottom, by means of which the cell may be filled with milk. Let us now suppose this cup to be filled with the milk to be tested, the screw having been previously turned until the plates of glass composing the cell are in contact. The milk in that case, will not pass between them, but will remain in the cup. Let the observer, applying his eye to the small end of the instrument, look through the cell at the flame of a candle, placed at about three feet distance from it, and let him at the same time slowly turn the screw, so as to let the milk flow into the cell ; at first the candle will be seen dimly through the milk, but when the plates have been separated by the screw to a certain distance, the flame will be no longer visible, being intercepted by the multitude of butter globules in the milk.

Now it will be found, as may be expected from what has been explained, that the poorer the milk is, the greater will be the distance to which the glasses must be separated in order to intercept the flame, and the richer it is, on the other hand, the less will be the distance which will suffice to produce that effect.

These instruments are made and sold by the Paris opticians.

98: It may be objected that the certainty of this instrument depends upon the fact that the milk is impoverished either by skimming it or by mixing it with water, but that if it be adulterated by any substance which will promote its opacity, the indications of the instrument must fail. The answer to this objection is, that such a mode of adulteration is impracticable ; the substance used for such a fraudulent purpose must in the first place be one, which, when mixed with the milk, will not sensibly alter its conspicuous and well-known properties, such as its colour, taste, odour, and general consistency. It must, moreover, be soluble in the milk, and not merely mixed with it, since if so, it would either sink to the bottom, forming a sediment, or rise to the top, as oil would in water, and in either case, would be immediately detected. It must also be such as will not be disengaged by heat, and thereby be betrayed in boiling the milk : in fine, it must obviously be a substance cheaper than milk, and the process of combination must be so simple as to be inexpensive and to admit of a certain secrecy ; now it is quite apparent, that there is one substance only which will fulfil all these conditions, and that substance is water.

99. The frauds practised by the vendors of milk do not always

consist in adulteration ; we have already mentioned the case of skimming the milk, and selling the richer and poorer portions at different prices ; this cannot be characterised as fraud, so long as the difference of quality is admitted, but yet it has the effect of fraud upon the consumer of the skimmed portion, for the milk he obtains is precisely the same in quality as he would obtain if the milkman instead of skimming the milk had left it in its natural state, but watered it, so as to reduce it to the poverty of skimmed milk.

100. There is another expedient, commonly enough practised, which is attended with similar effects, when the milk is allowed to accumulate in the breasts or dugs of the animal until they become filled and distended, the first portion drawn from them will be poor, and the milk will become richer and richer until the vessels are emptied. This physiological fact is quite familiar to dairymen, who divide the milking of the cow into two parts, the fore-milk and the after-milk ; the latter being sometimes called *strippings*. Now this richer portion of the milk is often reserved for cream, the fore-milk only being sold to the consumer. In accordance with the same principles it will be easily understood, that the more frequently the animal is milked, the more uniformly rich will be the fluid.

All the circumstances here explained, and the tests provided, to ascertain the quality of the milk of inferior animals, are equally applicable to human milk. Wet-nurses differ one from another evidently enough in the abundance of their milk, and this is a point which, accordingly, is never overlooked in the selection of nurses. The quality of the milk, however, being much less obvious, is rarely attended to. Yet it is even more important than the mere question of quantity. The physical researches of some of the French physiologists have shown that cases frequently occur in which there is a superabundance of milk ; and where, though the woman presents the aspect of health and vigour, the milk is poor in butter, the globules being small either in magnitude or number, or both ; they are sometimes observed to be ill-formed, to float in a liquid of little density, and sometimes to be mixed with corpuscles of mucus and of a granular substance. These are characters incompatible with the healthiness of the milk, yet they are such as can only be detected by the microscope. Nevertheless, it is rare indeed that the medical practitioner ever thinks of instituting such inquiries, much less of resorting to the microscope or any other lactoscopic test.

101. We have now indicated, so far as we are informed, all the methods by which the representations of microscopic objects are obtained, and of these that which gives the strongest guarantee of

accuracy and fidelity is the photographic method. It must, however, be observed, that even in this method, as it was practised in the production of the Microscopic Atlas of Messrs. Donné and Foucault, there is still a possible source of inaccuracy remaining, the engraver having to reproduce the photographic picture upon his plate, and for the fidelity of this process, there is no other guarantee than the general accuracy of the engraver's art.

Measures are, however, now being taken, with a fair prospect of success, by which an optical picture being projected upon a plate, will engrave itself—an approach to this has indeed been made; the photographic picture being projected upon a surface of wood, properly prepared and being there delineated by its own light, as it would be on a daguerreotype plate. The engraver after this has nothing to do but to follow the lines of the picture with his graving tool.

Attempts, however, are being made to cause the light itself to engrave the plate, and I have seen microscopic pictures of the blood corpuscles thus self engraved, which, if not completely satisfactory as works of art, have been sufficient to impress me with the conviction, that we are not far from the attainment of a measure of such high scientific importance as that of making natural objects engrave themselves.



LONDON ENTRANCE TO THE LONDON AND NORTH-WESTERN RAILROAD.

THE LOCOMOTIVE.

CHAPTER I.

1. Familiar to every eye.—2. Its mechanism not generally understood.—
3. Object of this Treatise.—4. Two modes of propelling wheel carriages.—5. How locomotive is propelled.—6. Action of piston-rod on wheels.—7. Dead points.—8. Unequal action.—9. How remedied.—10. Connection of piston-rods with wheels.—11. Wheels fixed on their axles.—12. Form of locomotive.—13. Driving-wheels.—14. Coupled wheels.—15. Consumption of steam.—16. Evaporating power of boiler determines efficacy of engine.—17. Fire-box.—18. Tubes through boiler.—19. Fuel.—20. Blast-pipe.—21. Tender.—
22. Plans and sections, with their description.

1. ALTHOUGH it be the variety of the steam-engine, whose invention is the most recent in date, the locomotive is the form of the machine which is most familiar to the public in every country. To behold the vast engines used for drainage, mining countries

THE LOCOMOTIVE.

must be visited ; to see those adapted to useful machinery, we must go to the factories ; to view those applied to navigation, we must descend into the holds of ships. The locomotive, however, needs not be sought. It is patent and obtrusive. It addresses the senses of hearing and seeing. The warning whistle and the snorting chimney are familiar to every ear, and the flashing speed of the engine, with its snake-like appendage of vehicles of transport, is familiar to every eye.

2. Of the countless multitudes in all civilised countries who witness the extraordinary performances of the locomotive, and participate in its use and enjoyment, few comprehend the source of its power, or the principle of its action. They see it sweep along with the speed of the hurricane, drawing after it carriages, carrying hundreds of human beings, or hundreds of head of cattle, or tons of goods, but the agency which accomplishes this miracle is to them wrapt in mystery. Many desire to possess the key to the enigma, to unlock the secret, but recoil from the labours which the perusal and study of even the most popular treatise on the locomotive would require, a labour for which few have the disposable time, and still fewer the qualifications depending on preliminary knowledge and intellectual aptitude.

3. It is this multitude that we now desire to address, hoping to offer, in a small compass, such a simple and clear account of the variety of steam-engine referred to, as will be intelligible to all persons, without more labour than all can conveniently devote to it.

4. A moving power may be applied in two ways to propel a vehicle supported on wheels. It may be harnessed to it as horses to a carriage, and may draw it on by traces, or it may be applied to the wheels, so as to make them revolve. If the wheels be made to revolve, they must either slip upon the road, or the vehicle must advance. But if the weight upon them be considerable, and the state of the road suitable, they will have such adhesion with the road at the points where they rest upon it, that they will not in general slip ; and if they do not, the vehicle which they support must be propelled by each revolution of the wheels through a space equal to the external circumference of their tires.

5. Now it is by this latter means that the power of steam is applied to propel the locomotive. The steam pistons are connected by iron rods, called connecting-rods, either with the spokes of the wheels, at certain regulated distances from the axles, or with arms, called cranks, formed on the axles between the wheels. The force with which the pistons are alternately driven by the steam from end to end of the cylinders, is conveyed by the connecting rods to the spokes or cranks, and it acts upon them in the

ACTION OF PISTON ON WHEELS.

same manner as the arm of a man acts upon a windlass, thus imparting a continuous motion of revolution to the wheels.

6. To render this action of the piston on the wheels more apparent, the piston-rod, the connecting-rod, and the spoke or crank, are shown in fig. 1, in eight successive positions assumed by them during each revolution of the crank. The direction in which the connecting-rod acts upon the crank is indicated by the arrow.

The joint p unites the connecting-rod with the end of the piston-rod, and the joint r unites it with the end of the crank or spoke, the fixed centre round which the crank or spoke revolves being c .

While the piston makes a double stroke from one end of the cylinder to the other and back, the joint r makes one complete revolution round the centre c .

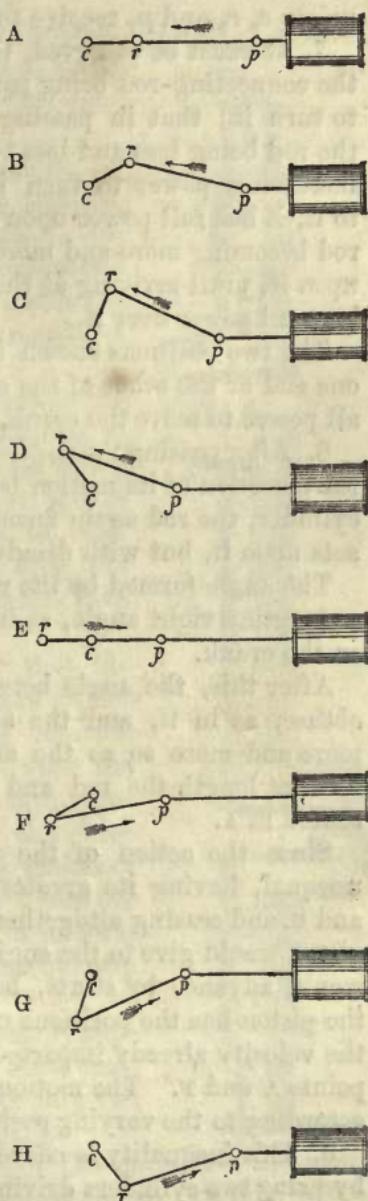
In the position shown in A, the piston is at the end of the cylinder most remote from the crank, and the joint r is directly between the centre c and the joint p .

In the position B, the joint r has moved from that position, the piston moving towards c , and the connecting-rod and crank forming an obtuse angle. The force of the steam impelling the connecting-rod in the direction shown by the arrow, acts at an obtuse angle with the crank.

As the piston continues to move, the angle formed by the connecting-rod and crank becomes less and less, until in the position shown in C the angle becomes a right angle, and then the whole force given to the connecting-rod becomes effective.

In the position D, the angle formed by the connecting rod and crank becomes acute, and in the position E, the joint r assumes a position in a direct line with c and p , and the piston has reached

Fig. 1.



THE LOCOMOTIVE.

the end of the cylinder nearest to *c*. After this the piston begins to move from *c* towards the more remote end of the cylinder, and the joint *r* assumes successively the positions shown in *F*, *G*, and *H*, the crank making first an acute angle, then a right angle, and, in fine, an obtuse angle with the connecting-rod, until the piston has arrived at the more remote end of the cylinder, when the points *c*, *r*, and *p*, receive the position shown in *A*.

7. It must be observed, that in the positions shown in *A* and *E*, the connecting-rod being parallel to the crank, can have no power to turn it; that in passing from the position *A* to the position *c*, the rod being less and less oblique to the crank, has a continually increasing power to turn it, until at *c*, being at right angles to it, it has full power upon it. After passing the position *c*, the rod becoming more and more oblique to *c*, has less and less power upon it, until arriving at the position *E*, it is parallel with it, and loses all power over it.

The two positions shown in *A* and *E*, in which the piston is at one end or the other of the cylinder, and in which the piston loses all power to move the crank, are called the DEAD POINTS.

8. After passing the position *E*, when the piston, having changed the direction of its motion begins to return to the other end of the cylinder, the rod again forms an acute angle with the crank, and acts upon it, but with disadvantage, as shown in *F*.

The angle formed by the rod and the crank increasing, becomes at length a right angle, as in *G*, when the rod acts with full effect on the crank.

After this, the angle between the rod and the crank becomes obtuse, as in *H*, and the action is again disadvantageous, and more and more so as the angle becomes more and more obtuse, until at length the rod and crank return to the position represented in *A*.

Since the action of the piston upon the wheel is, therefore, unequal, having its greatest efficiency at the points shown in *c* and *G*, and ceasing altogether in the positions *A* and *E*, a single piston would give to the engine an unequal progressive motion. It would advance by starts, being impelled with most effect when the piston has the positions *c* and *G*, and moving only in virtue of the velocity already imparted to it when the piston is at the dead points *A* and *E*. The motion would be alternately fast and slow, according to the varying position of the connecting-rod and crank.

9. This inequality is effaced, and an uniform motion obtained by using two cylinders driving different cranks or different wheels, and so arranging them, that when either is at its dead points, the other is in its positions of greatest efficiency. This is accomplished simply by placing the two cranks at right angles to each other, or

CRANKED AXLE.

by connecting the rods with spokes at right angles to each other. By such an arrangement, the combined effects of the two cranks will be invariable, or nearly so, the effect of either increasing exactly as that of the other decreases.

10. The cylinders are sometimes placed between and sometimes outside the wheels.

If they are placed between one pair of wheels the axle of another pair is formed with two cranks, placed at right angles to each, which are worked by the connecting-rods of the pistons.

Such a double-cranked axle is shown in fig. 2, the cranks being seen in a position oblique to the plane of the diagram. The connecting-rods are understood to be attached to the cranks at B, and the wheels, which are to be driven, are keyed upon the extremity of the axle at G.

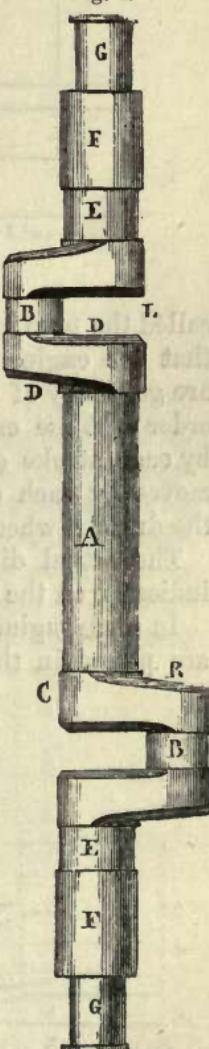
When the cylinders are placed outside the wheels, the connecting-rods are attached to two spokes, one upon each of the wheels which they are intended to drive, these two spokes being in positions at right angles to each other, and the wheels being keyed upon the axles, so that the wheels and axles turn together.

11. It may be stated generally that the wheels of railway vehicles and engines do not turn upon their axles like those of common road carriages, but are always fixed upon the axles, so that the wheel and axle turn together, and, consequently, whether the force of the connecting-rods act upon the spokes of the wheels, or upon cranks formed upon the axle, they will be equally efficient in imparting rotation to the wheels and consequently impelling the engine.

12. The locomotive engine is commonly supported on three pairs of wheels. In some cases of small and light engines there are only two pairs, and in others there are four pairs.

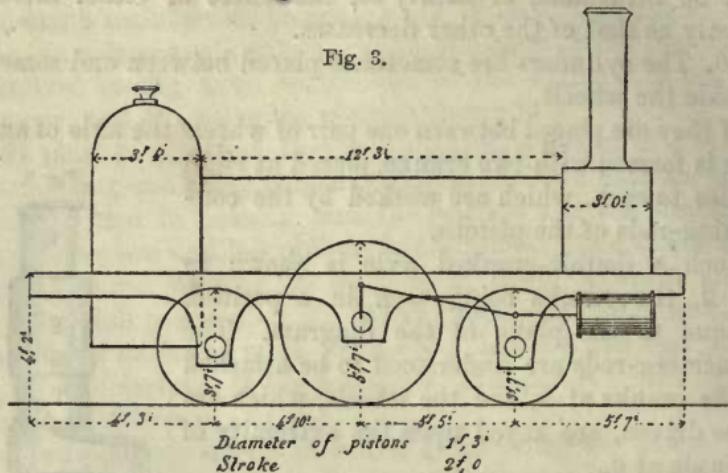
The general form and disposition of the parts of a locomotive upon three pairs of wheels is shown in fig. 3. In this case the two cylinders are placed immediately in front of the fore wheels and under the chimney. The intermediate pair of wheels are driven by the connecting-rods.

Fig. 2.



THE LOCOMOTIVE.

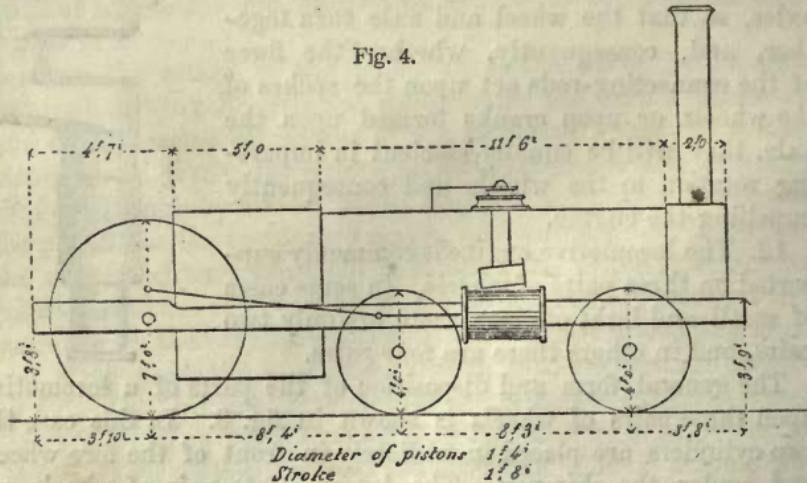
13. The pair of wheels to which revolution is imparted by the piston-rod, through the intervention of the connecting-rods, are



called the DRIVING-WHEELS, since it is by their immediate action that the engine draws the train which is attached to it. They are generally of greater diameter than the supporting-wheels, in order that the engine may be propelled through a greater space by each stroke of the piston, since the space through which it moves by each double stroke is equal to the circumference of the driving-wheels.

The actual dimensions of such an engine as is represented, are indicated on the diagram.

In some engines of more recent construction the driving-wheels are placed in the hindermost part of the engine, the cylinders



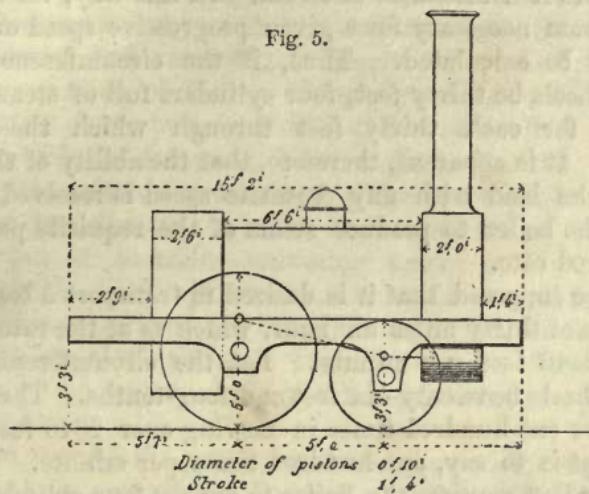
being between the intermediate and foremost pairs of wheels, as

DIFFERENT FORMS OF LOCOMOTIVES.

represented in fig. 4. In these the driving-wheels are of greater dimensions, and the engine is adapted to attain greater speed.

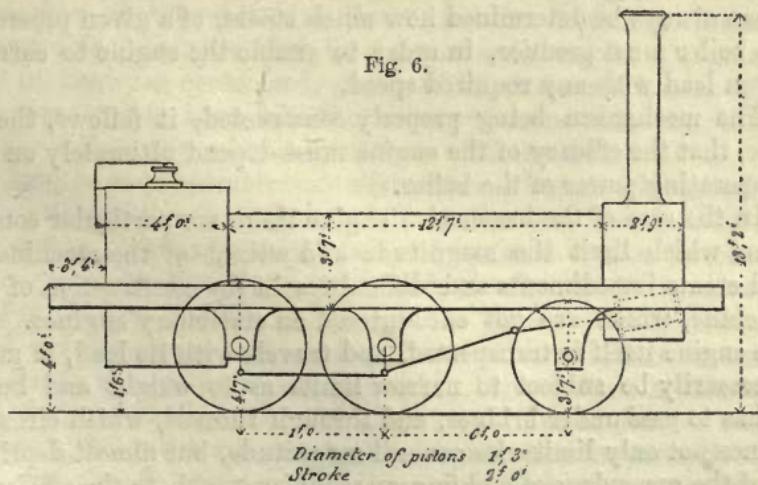
A lighter and less powerful class of locomotive, supported on two pairs of wheels, is shown in fig. 5, the hinder pair being the driving-wheels.

Fig. 5.



14. When locomotives are intended to draw very heavy loads with less speed, as in the case of goods engines, the driving-wheels have less dimensions, and, in order to give them a greater hold upon the rails, it is usual to connect two pair of side wheels, of exactly equal dimensions, so that the piston shall act at once on both by means of the connecting-rods. The two pair of driving-wheels thus connected are said to be COUPLED, and the engine is

Fig. 6.



called a coupled-engine. Such an engine is shown in fig. 6, where the hinder and intermediate pairs are coupled, the connect-

THE LOCOMOTIVE.

ing-rods being attached to the intermediate pair, and through them acting also on the hinder pair.

15. It has been shown that to give a revolution to the driving-wheels, each of the pistons must move once backwards and forwards in the cylinder, and consequently the boiler must supply to the cylinders four measures of steam. In this way, the consumption of steam necessary for a given progressive speed of the carriage may be calculated. Thus, if the circumference of the driving-wheels be thirty feet, four cylinders full of steam will be consumed for each thirty feet through which the carriage advances. It is apparent, therefore, that the ability of the engine to move the load with any requisite speed is resolved into the power of the boiler to produce steam of the requisite pressure at this required rate.

Let it be supposed that it is desired to transport a certain load at the rate of thirty miles an hour, which is at the rate of half a mile, or 2640 feet per minute. Let the circumference of the driving-wheels be twenty-six feet and four-tenths. These wheels will revolve one hundred times in moving over 2640 feet, or half a mile, that is to say, one hundred times per minute. But since each revolution requires the boiler to supply four cylinders full of steam, the consumption of steam per minute will be four hundred times the contents of the cylinder.

16. The pressure of the steam will depend upon the resistance of the load. By the common principles of mechanics, the power acting upon the pistons necessary to balance a given resistance at the circumference of the wheel can be easily calculated, and thus the necessary pressure of the steam ascertained. In this manner it can always be determined how much steam, of a given pressure, the boiler must produce, in order to enable the engine to carry a given load with any required speed.

The mechanism being properly constructed, it follows, therefore, that the efficacy of the engine must depend ultimately on the evaporating power of the boiler.

In the case of the locomotive engine there are particular conditions which limit the magnitude and weight of the machinery, and create impediments and difficulties in the construction of the machine, which are not encountered in stationary engines. As the engine itself is transported, and travels with its load, it must necessarily be subject to narrow limits as to weight and bulk. It has to pass under bridges, and through tunnels, which circumstance not only limits its general magnitude, but almost deprives it of the appendage of a chimney, so indispensable to the efficiency of stationary steam-engines.

It follows that this limitation of weight and bulk can only be

EVAPORATING POWER—FURNACE.

rendered compatible with great power of evaporation by expedients which shall produce, in a small furnace, an extremely intense combustion, and which shall ensure the transmission to the water completely, and immediately, of the heat developed in such combustion.

17. The heat developed in the combustion of fuel in a furnace is propagated in two ways. A part radiates from the vivid fuel in the manner, and according to nearly the same laws which govern the radiation of light. These rays of heat, diverging in every direction from burning fuel, strike upon all the surfaces which surround the furnace. Now, as it is essential that they should be transmitted immediately to the water in the boiler, it follows that the furnace ought to be surrounded on every side with a portion of the boiler containing water; in short, a hollow casing of metal, filled with water, ought to surround the fireplace. By this expedient, the heat radiating from the fuel, striking upon the metal which forms the inner surface of such casing, will enter the water, and become efficient in producing evaporation.

Whatever then be the particular form given to the engine, the furnace must be surrounded by such a casing. This casing is called the FIRE-BOX. The bottom of it is occupied by a grate, which should consist of bars sufficiently deep to prevent them from being fused by the fuel which rests upon them, having sufficient space between them to allow the air to enter so freely as to sustain the combustion, but not such as to allow the unburned fuel to fall through them.

18. The limited magnitude of locomotive boilers renders the construction of the extensive flues used in stationary boilers impracticable; and accordingly, in the early engines, a great waste of heat was occasioned, owing to the flame and heated air being permitted to issue into the chimney before their temperature was sufficiently reduced by contact with the flues.

At length an admirable expedient was adopted which completely attained the desired end. The boiler was traversed by a considerable number of small tubes of brass or copper, running parallel to each other from end to end, the furnace being at one end of the boiler, and the chimney at the other. The flame and heated air which passed from the furnace had no other issue to the chimney except through these tubes. It was thus driven, in a multitude of threads, through the water. The magnitude and number of the tubes was so regulated, that when the air arrived at the chimney, it had given out as much of its heat as was practicable to the water.

The full importance of this expedient was not appreciated until

THE LOCOMOTIVE.

long after its first adoption. In the first instance, the tubes traversing the boiler were small in number, and considerable in diameter, but as their effects were rendered more and more evident by experience, their diameter was diminished and their number increased, and at length it was not uncommon for the boiler to be traversed by one hundred and fifty tubes of one inch and a half in internal diameter.

The heat was thus, as it were, strained out of the air before the latter was dismissed into the chimney.

These tubes were necessarily kept below the surface of the water in the boiler, so that they were constantly washed by the water, and the heat taken up from them was absorbed immediately by the bubbles of steam generated at their surface, which bubbles continually rose to the top of the boiler and collected in the steam chamber.

It will be understood from these observations, that the evaporating power of the locomotive boiler, is determined by the quantity of surface exposed to the radiant heat in the fire-box and the quantity of surface exposed to the action of the heated air in the tubes. The expression of the quantity of this surface in square feet is the usual test of the evaporating power of the boiler.

19. Much of the efficacy of these boilers depends on the quality of the fuel. As the engines travel through districts of the country more or less populous, the evolution of smoke is inadmissible in consequence of the nuisance it would produce. It was, therefore, resolved to use coke as fuel instead of coal.

Another advantage, however, attended the use of this fuel. Coke being composed chiefly of carbon, to the exclusion of the more volatile constituents of coal which produce flame in the combustion, the chief part of the heat developed acts by radiation. No flame issues from the furnace, and heated air only passes through the tubes. It is more easy, therefore, to extract the heat than would be the case if flame were developed. In short, with this fuel, the portion of the heat developed in the furnace is much greater than that which would be developed in the combustion of coal. The surface of the fire-box becomes relatively more efficient, and the flues less so than in stationary engines where coal is used.

Independently, therefore, of the advantage of developing no smoke, the coke is a form of fuel better adapted to the condition of the locomotive engine.

20. To sustain a rapid and intense combustion on a grate necessarily small, a proportional force of draft is indispensable. In stationary engines, as is well known, the draft in the furnace is usually produced by a chimney of corresponding elevation; but

BLAST PIPE—FEED PUMPS.

this being inadmissible under the conditions of the locomotive engine, it is necessary to adopt some other expedient to produce the necessary current of air through the tube. A blower, or fanner, working in the funnel or in any other convenient position, would answer the purpose ; but a much better expedient has been adopted.

The steam, after driving the piston, is allowed to escape, but in order to turn it to profitable account, instead of being dismissed into the atmosphere, where it would produce a cloud of vapour around the engine, it is conducted through a pipe to the base of the funnel, where it is allowed to escape in a jet directly up the chimney. In this manner a puff of waste steam escaping from the cylinders as the pistons arrive at the one end or the other, is injected into the chimney, and a constant succession of these puffs take place, four being made for every revolution of the driving-wheels. These continual puffs of vapour maintain in the chimney a constant current upwards, by which the air and gases of combustion are drawn from the fire-box through the tubes.

The pipe by which these jets are directed up the chimney, called the *blast-pipe*, serves the purpose of a most efficient bellows.

Those who are not familiar with steam machinery will not find it difficult to comprehend that a bellows would produce the same effect on the fire if it acted in the chimney, or even at the top of the chimney, as if it were applied at the grate bars, provided only that the mouth of the chimney near the fire be closed by a door, as it always is in steam-engines.

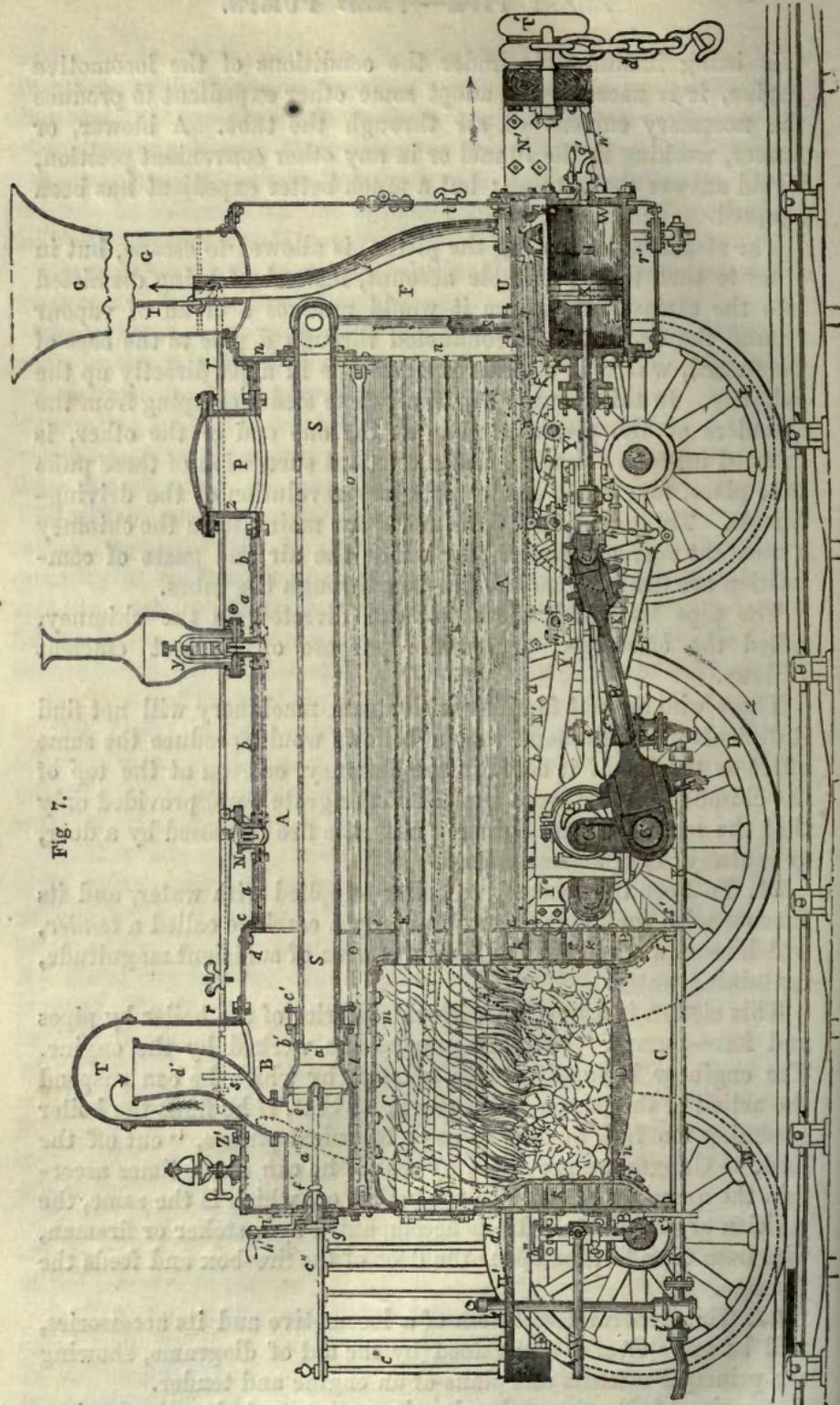
21. To keep the locomotive boiler supplied with water, and its furnace with fuel, it is accompanied by a carriage called a *tender*, which bears a supply of fuel, and a cistern of sufficient magnitude, containing water.

This cistern is connected with the interior of the boiler by pipes and force-pumps. The force-pumps are worked by the engine. The engineer is supplied with a lever, by which he can suspend the action of the pumps at pleasure ; so that, if he finds the boiler becoming too full, he can, to use a technical phrase, "cut off the feed." Gauges are provided, by which he can at all times ascertain the quantity of water in the boiler, or, which is the same, the position of its surface. He is accompanied by a stoker or fireman, who from time to time opens the door of the fire-box and feeds the furnace.

22. This general description of a locomotive and its accessories, will be more clearly understood by the aid of diagrams, showing the principal sections and plans of an engine and tender.

A series of drawings, showing in section and elevation various

Fig. 7.



PLANS AND SECTIONS OF ENGINE.

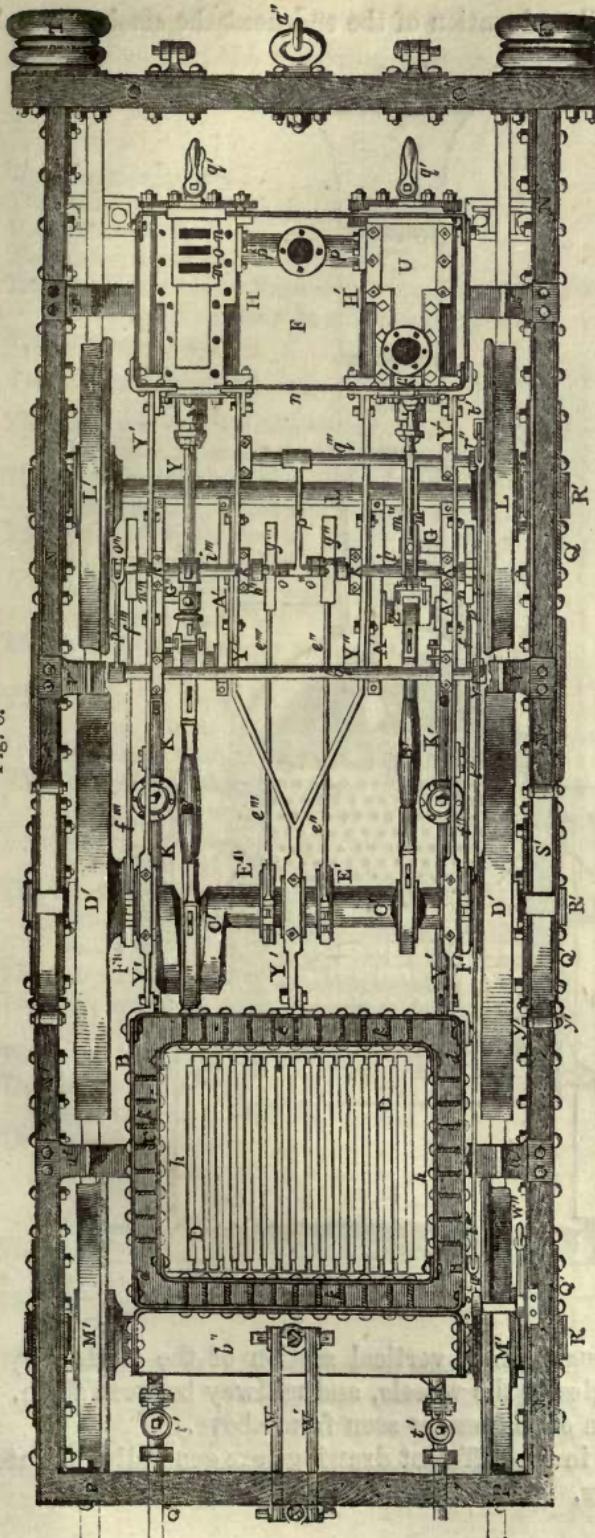


Fig. 8.

views of a locomotive engine on three pairs of wheels with its tender, is given in figs. 7, 8, 9, 10, 11, 12, 13, and 14.

Fig. 7 is a longitudinal vertical section, made by a plane parallel to the wheels, and passing through the axis of the boiler and the smoke-funnel.

Fig. 8 is a
plane of the
working machi-
nery between the
wheels and be-
neath the boiler.

Fig. 9 is transverse vertical section made by a plane passing through the fire-box at right angles to the wheels.

Fig. 10 is a similar transverse section, made by a plane passing through the smoke-box and the axis of the smoke-funnel.

Fig. 11 is an elevation of the end of the engine near the driver's stage.

THE LOCOMOTIVE.

Fig. 12 is a similar elevation of the end next the smoke-funnel.

Fig. 9.

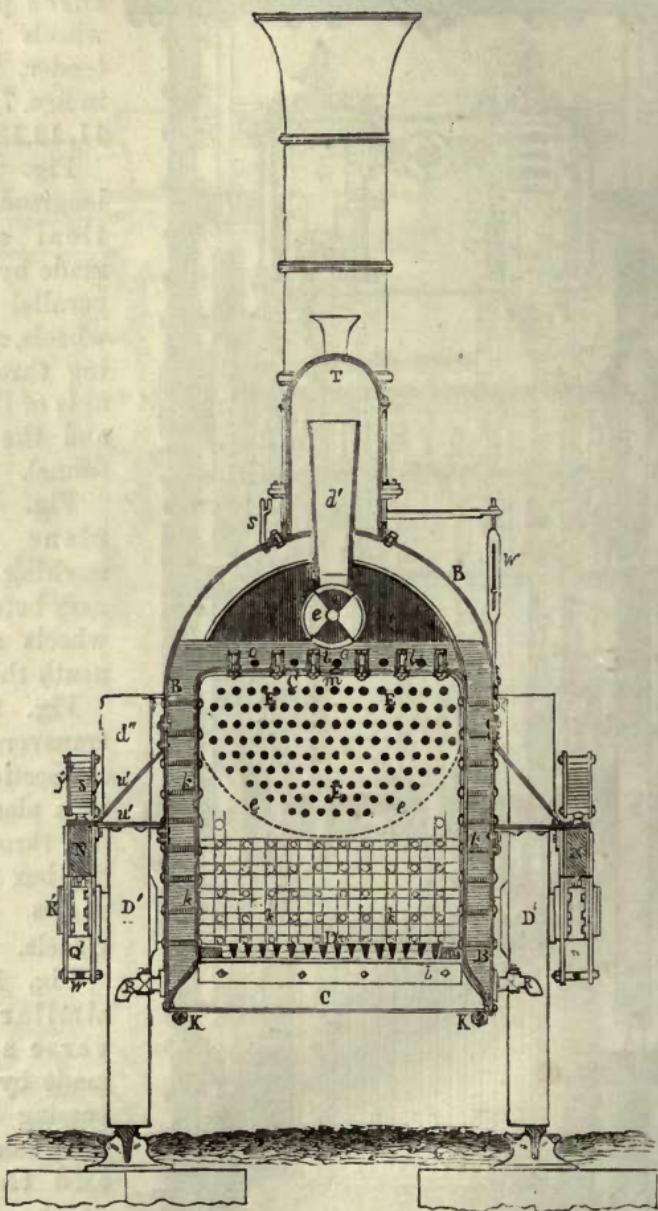


Fig. 13 is a longitudinal vertical section of the tender, by a plane at right angles to the wheels, and midway between them.

Fig. 14 is a plan of the tender seen from above.

The same parts in the different drawings are generally indicated by the same letters.

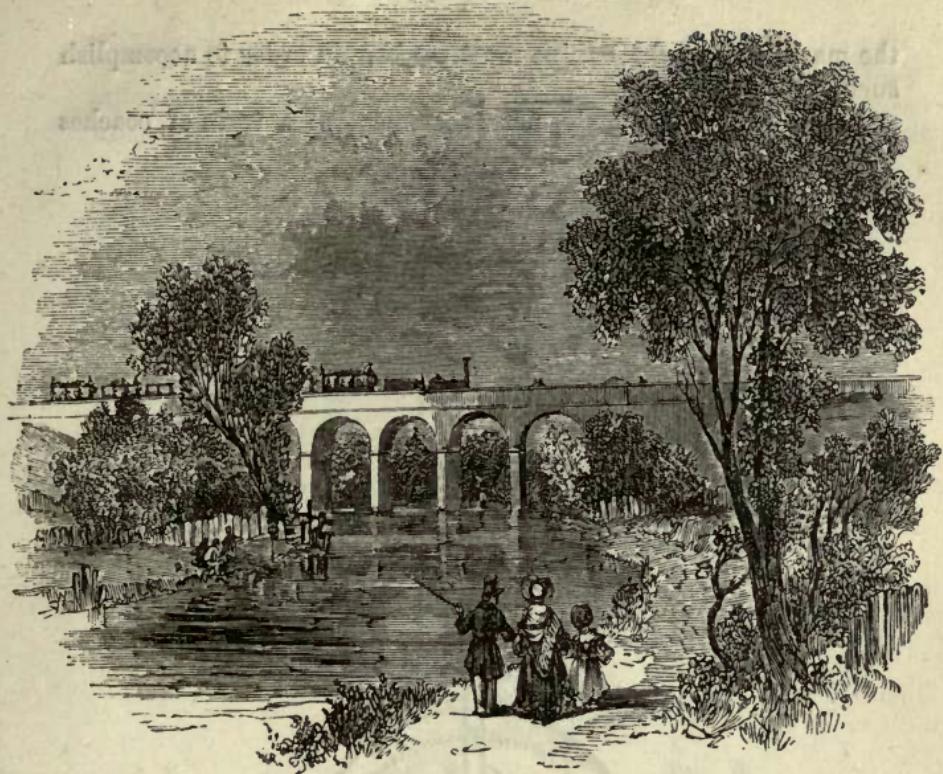
PLANS AND SECTIONS.

The principal parts will be recognised by the preceding general description, and the following references:—

	Number of diagram.	Letters of reference.
The steam cylinders	7, 8	H
The steam pistons	7	X
The piston-rods	7, 8	Y
The connecting-rods	7, 8	B'
The cranks driven by them which in this case are constructed on the axle of the driving-wheels	7, 8	C'
The driving-wheels	7, 8, 9	D'
The supporting-wheels	7, 8, 10, 11, 12	L, M
The passages to allow the entrance and escape of the steam to and from the cylinder	8	m, n, o
The case containing the slide by which these passages are opened and closed	8	U
Two pair of eccentrics by which the slides are moved, one governing the steam so as to move the engine forward, and the other so as to move it backward	8	E' E'', F' F''
The rods by which these eccentrics act upon those of the slides	8	e'' e''', f'' f'''
The handle or lever by which the engine driver throws one or other pair of eccentrics into connexion with the slides	7	a'''
The steam-chest, where dry steam free from mixture with aqueous spray is received from the boiler	7, 11	T
The steam-pipe leading from this chest by which steam flows to the slides and to the cylinder	7	S S
The blast-pipe, by which steam, after entering the piston, is discharged in puffs up the smoke-funnel	7, 10	p
The fire-box containing the burning coke	7, 9	C C
The hollow metal casing surrounding it secured by bolts and nuts, and filled with water	7, 8, 9	k k
The grate bars forming the bottom of the fire-box	7, 8, 9	D
The fire door through which coke is put in from time to time to feed the furnace	11	g
The tubes traversing the boiler longitudinally through which the hot gases of combustion and smoke pass from the fire-box to the smoke-box	7, 9, 10	E E
The smoke-box at the base of the funnel, receiving the heated air from the tubes	7, 8, 10	F
The smoke-funnel over the smoke-box and blast-pipe	7, 10, 12	G
The regulator, by which more or less steam is allowed to pass along the steam-pipe, and by closing which the steam is altogether cut off from the cylinder	7	h'
The stage upon which the engine driver and stoker stand	7, 11	P' c''

THE LOCOMOTIVE.

	Number of diagram.	Letters of reference.
The water gauge, being a glass tube communicating above and below with the interior of the boiler, in which the water stands at the same level as in the boiler	11	L
Gauge-cocks, which serve a like purpose, one being below and the other above the proper level of the water. If the water be below the proper level, steam would issue from the lower, and if above it, water would issue from the upper cock	11	M
The feed-pump, being a force-pump worked by the engine, by which water is forced into the boiler from time to time to replace that which is evaporated	7, 8	K'
The feed-pipe, leading from the feed-cistern on the tender to the feed-pump	7	K
The levers by which the engine driver governs the feed. These open or close the feed-pipe according as they are turned one way or the other. When the engine driver sees the level fall too low in the water gauge or by the gauge-cocks, he opens the feed-pipe by these cocks and puts on the feed, and when it has risen to the proper point he closes them. There are usually two feed-pumps, with their appendages	11	<i>t' t'</i>
The smoke-box door, opening on hinges at the top by which that part of the engine may be cleaned	12	t
The buffers, being circular cushions fixed upon the ends of strong iron rods, which re-act against spiral springs, to break the force in case of collision	7, 12	T T'
The heads of the cylinders, which are secured by bolts and nuts, and can be taken off for the purpose of cleansing the ash-pit	12	W W
The feeding cistern on the tender	13, 14	I"
The feed-pipe proceeding from it	13	P" Q"
The coupling of the parts of the feed-pipe attached to the engine and the tender	13	P"
The coupling bar of the tender and engine	13	W"
The coupling chain of tender and train	13	Y"
The buffers of the tender	13, 14	D"
The lids of the feed-cistern	14	N"
The handle of the brake upon the tender	14	X"
The space for coke	14	B"



VIADUCT, NEAR WATFORD, LONDON AND NORTH-WESTERN RAIL-ROAD.

THE LOCOMOTIVE.

CHAPTER II.

23. Speed.—24. Locomotive stock.—25. What record of the performance and condition of an engine should be kept.—26. Cause of renewals of English locomotives.—27. Average mileage of engines.—28. Locomotive requires rest.—29. Expense of cleaning and lighting.—30. Reserve engines.—31. Bank engines.—32. Time they are kept standing.—33. Economy of fuel.—34. Register of consumption.—35. Small amount of useful service obtained.—36. On Belgian lines.—37. On other Continental lines.—38. On London and North Western line.—39. Comparisons between lines not fairly instituted.—40. Legitimate test of comparison.—41. Amount of locomotive stock required.—42. Gross receipts of European Railways in 1850.—43. Mileage of the same.—44. Great increase since.—45. Enormous consumption of coal.—46. Mileage of passengers and goods.

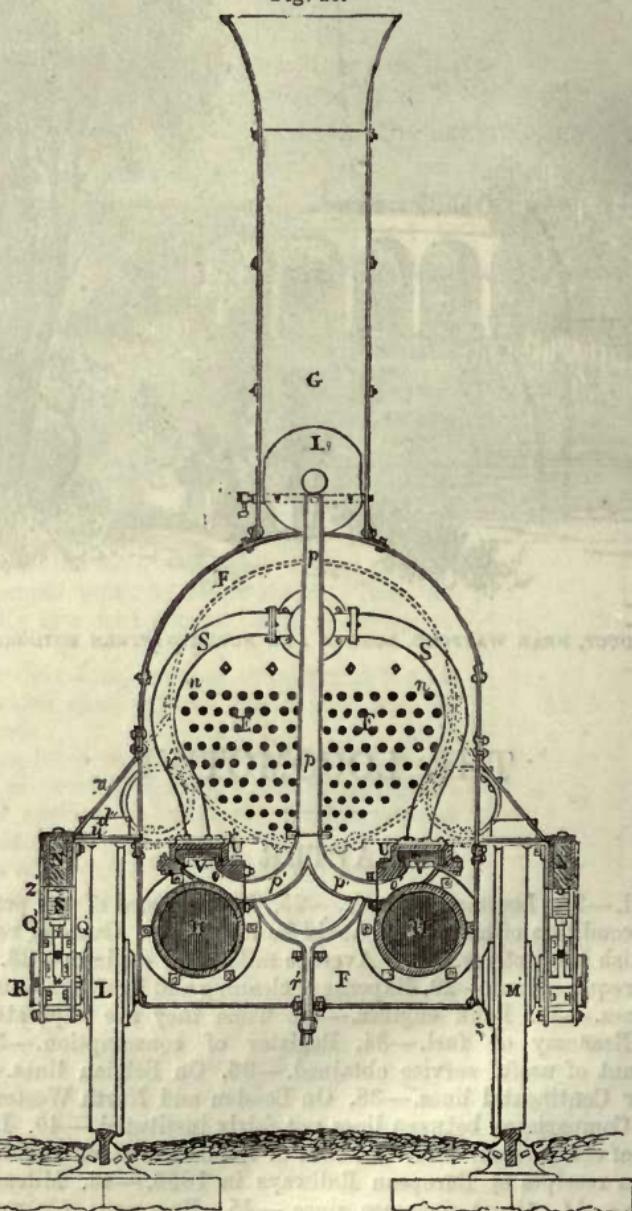
23. WHEN the extraordinary speed sometimes imparted to the loads drawn by locomotive engines on the English railways is considered, it will not be uninteresting to explain what operations

THE LOCOMOTIVE.

the machinery of the engine must perform in order to accomplish such effects.

Let us take the example, not uncommon, of a train of coaches

Fig. 10.

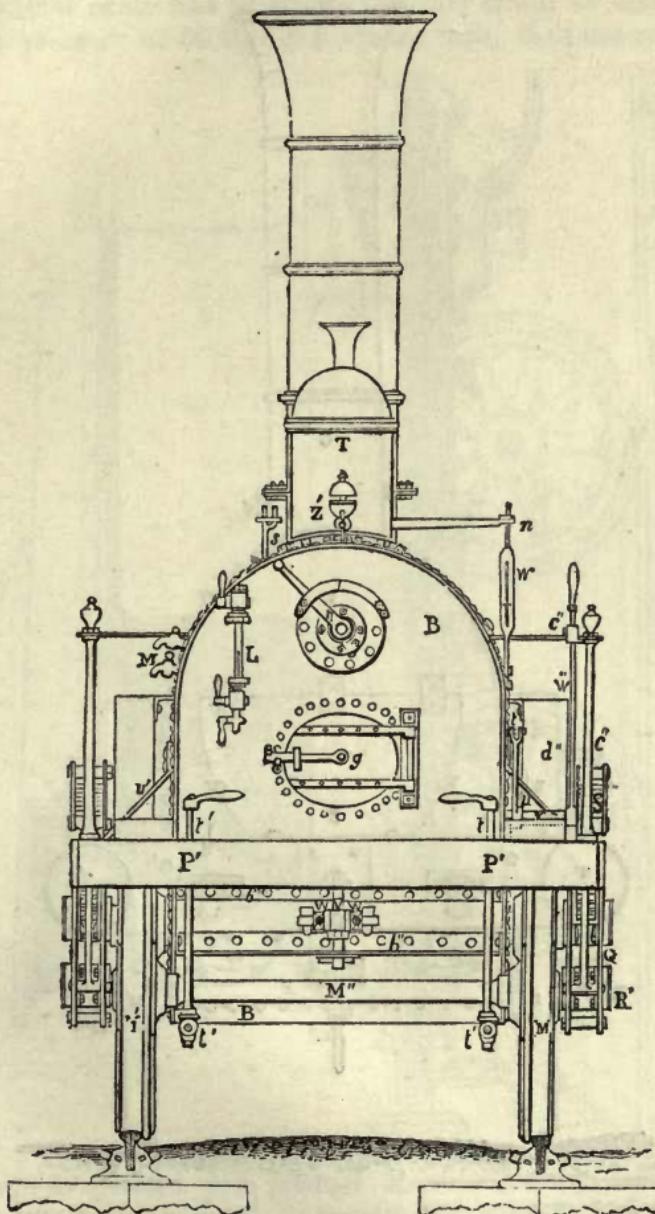


carried upon a railway, at a rate of sixty miles per hour. Assuming, as in a former example, that the circumference of the driving wheel measures $26\frac{4}{10}$ feet, these wheels, as already explained, will revolve one hundred times in passing over half a mile, and there-

OPERATION OF ENGINE.

fore two hundred times in passing over a mile. The speed of sixty miles an hour is that of a mile per minute. The driving wheels will, therefore, revolve two hundred times per minute. But it

Fig. 11.

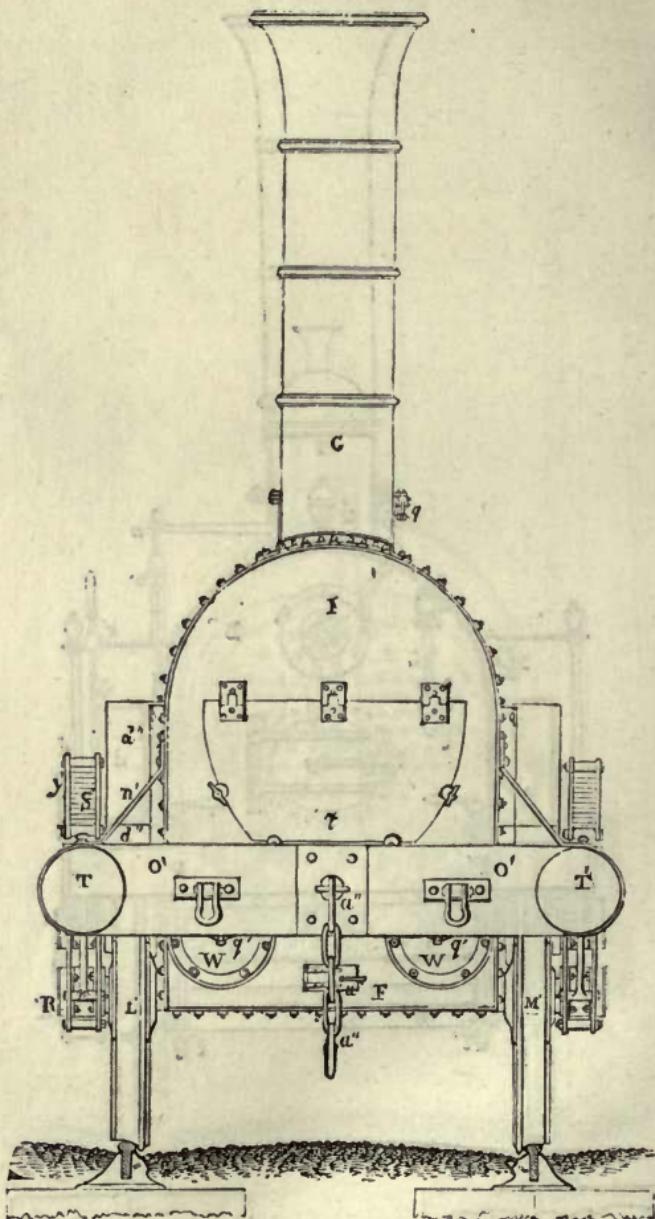


has been already explained that to produce one revolution of the wheels each piston is moved once backwards and forwards in each cylinder, and each cylinder must be twice filled with steam from

THE LOCOMOTIVE.

the boiler, and that steam must be twice discharged from each cylinder through the blast pipe. It follows, that to accomplish the speed above mentioned, the boiler must supply to the cylinders

Fig. 12.



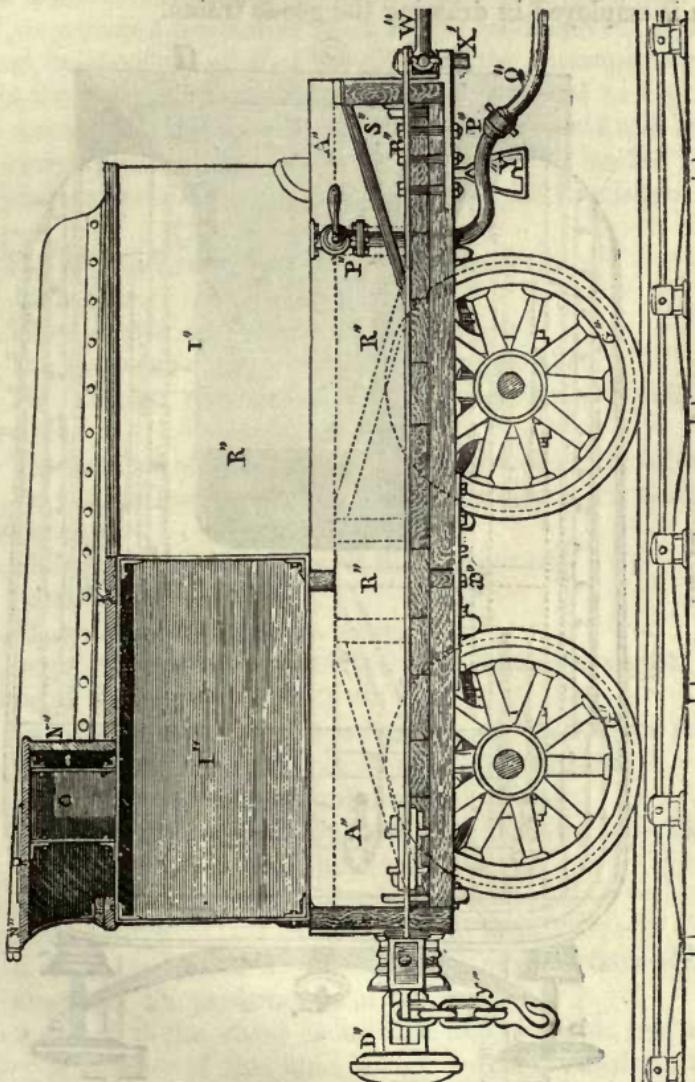
eight hundred measures of steam of the requisite pressure per minute. The valves which admit this steam to each cylinder must be opened four hundred times per minute, as must also both valves

NECESSARY EVAPORATION.

by which the steam is ejected. The puffs from the blast-pipe must be made at the rate of eight hundred per minute.

If we assume that the contents of each cylinder is one cubic foot and a quarter, then the boiler must supply to the cylinder per minute 1000 cubic feet of steam. If this steam be assumed to have a pressure of 50 lbs. per square inch, then one cubic foot

Fig. 13.



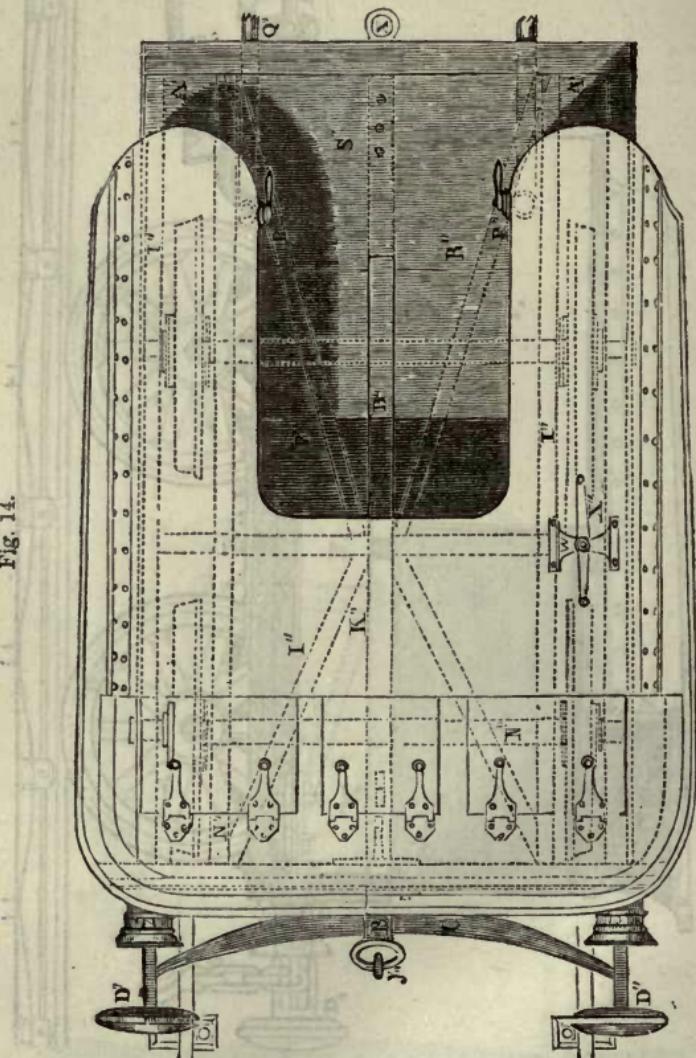
of water evaporated will produce about 500 cubic feet of such steam; and consequently, to supply 1000 cubic feet of steam per minute to the cylinders, the boiler must evaporate two cubic feet of water per minute, or 120 cubic feet per hour. This is a rate of evaporation which would correspond to a stationary boiler of a nominal power of 120 horses.

THE LOCOMOTIVE.

24. When the magnitude of the capital invested in the locomotive stock of a railway, and the large proportion of the annual revenue absorbed in maintaining it are considered, its economical importance may be readily estimated.

The locomotive stock may be primarily resolved into two classes—that which is employed in working the passenger traffic, and that which is employed in drawing the goods trains.

Fig. 14.



The passenger engines are so constructed as to draw light loads at great speed, the goods engines heavy loads at a low speed. In the one, the driving-wheels are large, so as to carry the train forward through a great space by each stroke of the piston; in the other, they are of more limited magnitude, in order to give the moving power a greater leverage upon the load. In the one, they

LOCOMOTIVE REGISTER.

are single, rendering the engine light, so as to absorb less of the moving power in propelling itself; in the other, they are double and coupled, and sometimes even tripled, so as to give a greater purchase to the impelling power. In the one class of engine steam of small density is consumed rapidly and in great volume; in the other, steam of greater density is consumed at a slower rate.

These different mechanical requirements render it necessary, in general, to provide a locomotive stock for the goods service, separate from, and independent of, that provided for the passenger service.

25. In the locomotive department a register should be kept containing a record of the past and current performances and condition of every engine in the service of the railway. Such a record should contain the following particulars of the past services of each engine :—

- 1st. The day and year it was put upon the road.
- 2nd. Its maker.
- 3rd. The diameter and stroke of its cylinders.
- 4th. The diameter and number of its driving-wheels.
- 5th. The number of times it was cleaned, lighted, and had steam raised.
- 6th. The number of hours it was standing with steam raised.
- 7th. Its total mileage, from the commencement of its service to the current date.
- 8th. The total quantity of fuel it had consumed.
- 9th. Original cost of engine.
- 10th. Total sum expended on its repairs.

And, with respect to its current service during the past year, the following details should be given :—

- 1st. The number of times it was lighted, and had steam raised.
- 2nd. The number of hours it stood with steam raised.
- 3rd. Its mileage by months, and its total mileage.
- 4th. The quantity of fuel consumed in lighting and raising steam.
- 5th. The quantity of fuel consumed in standing.
- 6th. The quantity of fuel consumed in working.

7th. A memorandum of any accident, or other notable circumstance, attending the performance of the engine.

Such a record as the above is neither impracticable nor unimportant. A register of this kind is kept by the administration of the Belgian railways, and the principal results of it are published annually, in a tabulated form, in the "Compte Rendu," or official report of the service of the railways, delivered to the Chambers by the Minister of Public Works every session. Such a table exhibits a "coup d'œil" of the condition and the past history of the entire locomotive stock.

THE LOCOMOTIVE.

26. In the progress of the English railways, locomotives have been, from time to time, cast aside, and put, as it were, upon the retired list; but this has often arisen, not from the circumstance of their being superannuated, but because the conditions of the traffic had undergone such a change that the natural powers of these engines were not suited to it. Immediately after the commencement of the operation of the railway system, the traffic augmented so rapidly as to exceed all the previsions of those who constructed and organised the first railways. The weight and strength of the rails were successively increased, as well as the weight and magnitude of the trains, and the weight and power of the engines underwent a corresponding augmentation.

A regularly kept journal of the life of some of the oldest locomotives working on the English railways would be a record of profound interest. Whether such a register exists, I am not aware; but none such has, I believe, ever been published.

27. From a comparison of the total mileage of each class of the locomotive stock with the number of engines in service, the average mileage of each engine can be ascertained.

As an example of such a calculation, let us take the Belgian railways for 1847.

The total number of engines in active service was 154, and their total mileage was 2,366,885; this divided by 154 gives 15,369 as the average annual mileage of each engine, the average daily mileage being therefore 42 miles.

28. It may be asked, whether a locomotive engine, once lighted, may not be worked almost indefinitely?

It is known that many steam-engines used in the manufactures and in mining are kept for several months together in unceasing action night and day; and the engines used in steam-ships are often kept in incessant operation throughout a voyage of 3000 miles. Why therefore, it may be demanded, may not a locomotive engine be worked for a much longer distance without interruption, and thus distribute the expense of lighting and cleaning over a greater extent of mileage, and thereby diminish the cost per mile?

Although the mileage of the engine might be augmented much beyond its present amount, it is nevertheless indispensable that it should not exceed a certain practical limit. The locomotive engine, an iron horse, requires intervals of repose as much as do the horses of flesh, blood, and bones. It becomes fatigued, so to speak, with its work, and its joints become relaxed by labour, its bolts loosened, its rubbing surfaces heated, and often unequally expanded and strained. Its grate-bars and fire-box become choked with clinkers, its tubes become charged with coke; and were its labour continued

RESERVE ENGINES.

to a certain point, it would end in a total inability to move. The durability of the engine, therefore, requires that its work should be suspended before these causes of disability operate to an injurious extent.

When its labour ceases, the engine-cleaners, who are, as it were, its grooms, clean out its fireplace, scrape its grate-bars and the internal surface of the fire-box, clean out its tubes, tighten all its bolts and rivets, oil and grease all its moving parts, and, in a word, put it again into working order.

29. The expense of cleaning an engine, and the cost of the fuel consumed in lighting it and raising the steam, so as to prepare it for propulsion, must necessarily be charged upon the mileage which it performs ; and the cost of this mileage will therefore be augmented in the inverse proportion of the ratio of the total mileage of the engine to the number of times it has been cleaned and lighted during the period of its service. It is therefore important, in the economy of the locomotive power, to ascertain with precision the proportion which the mileage of the engines bears to the number of times they have been cleaned and lighted.

Hence appears the importance of the record above mentioned, of the number of times each engine has been lighted and cleaned.

To determine the average number of miles run by each engine after such cleaning and lighting, it is only necessary to divide the total mileage of the locomotive stock, or of each class of it, by the total number of engines lighted ; the quotient will give the distance run by each engine lighted.

In the practical working of the locomotive stock, it inevitably happens that engines, after they have been lighted, had their steam raised and prepared for starting, have to stand, keeping their steam up more or less time, waiting for trains which they are to draw ; and thus an expense is incurred, not directly productive, for fuel and wages.

30. But, besides this, the service of the road requires that, at certain stations, engines shall be kept waiting with their steam up ready for work, for the mere purpose of providing for the contingencies of the active service of the road. Thus, if an accident occur to a train, by which the engine that draws it is disabled, notice is sent forward by the electric telegraph, by signals or otherwise, to the next engine station, summoning an engine to proceed to the spot to take on the train. If an engine were not prepared for such a contingency, with its steam up, the road would be obstructed for a considerable length of time by the train thus accidentally brought to a stand.

The engines thus kept prepared for accidents are called *Reserve Engines.*

THE LOCOMOTIVE.

31. Another cause which renders it necessary at certain points of the line to keep engines waiting with their steam up, is the existence of exceptional gradients.

Thus, if a railway be generally laid out with gradients of about 15 feet a mile, but at a particular point a natural elevation of the ground, or other cause, renders the construction of a gradient rising at the rate of 60 feet a mile necessary, then the engines which are adapted to the general character of the line become insufficient for such exceptional gradient; and, in such case, the expedient resorted to is to keep one or more powerful engines constantly waiting with their steam up at the foot of the incline, for the purpose of aiding in propelling the trains in their ascent.

These engines are denominated *Assistant Engines* or *Bank Engines*. Their mode of operation is as follows. They wait near the foot of the incline in a siding provided for the purpose; and when a train arrives and begins to ascend, the assistant engine follows it, and, pushing from behind, aids the regular engine in front in propelling it up the plane. When it arrives at the summit, the assistant engine drops off, and, descending the plane, returns to its station.

32. It appeared from calculations, based on the preceding principles, which I made some years since, that on the Belgian lines the average distance run by each engine lighted was 78 miles, and on some of the French lines 76 miles. It also appeared that each engine lighted was kept seven and a half hours standing with steam up, including, of course, the reserve engines. Thus, it follows, that for every ten miles over which an engine works, it is kept an hour standing.

33. The fuel consumed in working a railway may be classed under three heads:—

1st. That which is consumed in lighting the engines and raising their steam, to prepare them for work.

2nd. That which is consumed while the engines stand with their steam up, waiting for the trains they are intended to draw, or standing in reserve, prepared for the contingency of accidents on the line.

3rd. That which is consumed in drawing the trains.

When the engine has stopped work, its fire-box is cleared, preparatory to the engine being cleaned. A certain portion of coke, more or less, according to the state of the fire-box at the moment the engine is stopped, is collected in this way half consumed. This coke is to a certain extent available to aid in lighting the engine when next started. The small coke which has been rejected as unfit for the working engine is mixed, in a greater or less proportion, by the engineer with the large coke used for

ECONOMY OF FUEL.

raising the steam, for in this process the draft is not so strong as to carry this small coke injuriously through the tubes. The small coke is also used, mixed in a certain proportion with the large coke, for keeping the steam up in the reserve engines.

The quantity of coke consumed in drawing a train will depend upon the magnitude and weight of the train, and the speed with which it is moved. The greater the resistance which it has to overcome, the greater will be the consumption of fuel in a given distance. The resistance increases in a high ratio with the speed. Now as the speed of passenger trains is usually greater than that of goods trains, the consumption of fuel, so far as it is affected by the speed, will be greater in the former than in the latter; but, on the other hand, goods trains consisting of a much greater number of vehicles and of a greater gross weight than passenger trains, the resistance due to the load is greater in the latter case than in the former.

On the Belgian railways the economy of fuel is very strictly attended to. Rules are established by which a certain weight of coke is allowed to the engineer for the different purposes.

For lighting and raising the steam, 280 kilogrammes, equal to 618 lbs., of coke are allowed.

For each passenger coach drawn, $\frac{3}{4}$ of a kilogramme per kilometre, equal to 2.64 lbs. per mile, are allowed.

For each loaded goods waggon, $\frac{2}{3}$ of a kilogramme per kilometre, equal to 2.35 lbs. per mile, are allowed.

Two empty waggons are accounted as equal to a loaded one, and $2\frac{1}{2}$ kilogrammes per kilometre, equal to 8.82 lbs. per mile, are allowed for an engine without a load.

Ten kilogrammes, equal to 22 lbs., per hour are allowed for keeping up the steam while an engine is standing.

These quantities are, however, understood to be average major limits which ought not to be exceeded. To stimulate the engineers and their superintendents to the observance of a due economy of fuel, premiums are awarded, in proportion to the extent of the saving effected upon these allowances; 5s. 6d. a ton is allowed to the engineer for every ton of coke by which his actual consumption falls short of these limits, and a further premium of one-fourth of this amount is allowed to the superintendents of the locomotive department.

34. In the locomotive department, a register should be kept of the fuel consumed, distinguishing such consumption under the three heads of standing, lighting, and working, together with which should be noted the hours standing, the engines lighted, and the mileage worked. There is nothing impracticable or difficult in the maintenance of such a register in every well-organised establishment, and such a one is regularly kept in the

THE LOCOMOTIVE.

administration of the Belgian railways. It appears from these records, that the following was the fuel consumed for these purposes respectively on the Belgian railways during the years 1846 and 1847:—

	1846.	1847.
Number of hours standing	204124	214610
Number of lbs. of coke consumed in standing	4,503077	5,306573
Average number of lbs. consumed per hour .	22°0	24°7
Number of engines lighted	27452	30676
Total number of lbs. consumed in lighting .	16,828505	18,605263
Average number of lbs. consumed per engine lighted	613°0	606°5
Total mileage worked	2,027014	2,366885
Total number of lbs. of coke consumed in working	60,698538	71,500965
Average number of lbs. consumed per mile worked	30°0	30°0
Average consumption per mile, including coke consumed in lighting and standing	40°5	40°3

It may then be stated in round numbers, that 600 lbs. of fuel are consumed in lighting an engine, and raising the steam, and that every engine lighted travels, on an average, as worked upon the Belgian lines, 70 miles.

The fuel consumed in lighting adds, therefore, $8\frac{1}{2}$ lbs. per mile to the working consumption, which latter being 30 lbs., the proportion consumed in lighting is 28 per cent. The fuel consumed in standing with steam up, either as an engine of reserve or otherwise, adds $1\frac{1}{2}$ per cent. more to the working consumption per mile, the total amount of which may be taken in round numbers at 40 lbs., as these railways are worked.

35. One of the most striking results of the calculations which I have made of the performance of locomotive engines as well in England as on the continent, is the small amount of useful service obtained from them.

36. It appears that in each run an engine, on the Belgian lines, at the most improved epoch of the service yet reported, did not quite average 78 miles, and that even this was performed only four days in seven. Thus the average daily work of an engine would appear to be only 44 miles.

But it also appears, that for 74 miles run the engine is kept, on an average, $7\frac{1}{2}$ hours standing. This being reduced to a daily average, leads to the conclusion, that the daily service of the engines consisted in 44 miles run and 4 hours standing with the steam up.

But as the average speed on the Belgian railway is about 20

MILEAGE OF ENGINES.

miles an hour, the run of 44 miles would occupy more than two hours.

The daily service of an engine, therefore, expressed in time, would be about 2 hours working and 4 waiting with steam up.

37. These inferences are so striking, that we naturally turn elsewhere to inquire how far the results of other railways vary from or corroborate them.

I accordingly made like calculations upon the statistical reports of most of the continental railways, and found that the average daily mileage of the engines is under 33 miles, being therefore inferior to the useful service of the Belgian engines.

38. The data supplied by the English railways are so scanty, and in general so vague, as to afford no adequate means of general comparison with the results above given. In the case of the London and North-Western lines however, a more detailed account was published, which, considering the great extent and traffic of that system of railways, is entitled to much attention.

The traffic of these lines was worked, during the twelve months ending June 30, 1849, by 457 locomotive engines, the total mileage of which was as follows:—

	Mileage.
Passenger engines	4,649556
Goods engines	2,882674
Total	<hr/> 7,532230

Hence the average daily run of each engine was 45 miles.

These results, obtained from services so various and numerous, leave no doubt that the average daily service of each locomotive engine is much less than would have been expected. If the average speed on the North-Western lines be taken at 28 miles an hour, we shall obtain the singular and somewhat unexpected conclusion, that the engines, taken one with another, are each worked with traffic little more than one hour and a half a day.

By a return which I obtained from the North-Western Company, I found that, in the twelve months ending June 30, 1849, they had in active employment an average number of 275 engine-drivers, and an equal number of firemen. Now it has already been stated, that during the same period the number of engines employed was 457; there were thus 10 engine drivers and firemen for every 16 engines.

By dividing the total annual mileage of the engines by the total number of engine-drivers and firemen employed, we shall find the total annual distance driven by each; and dividing this by 365, we shall obtain the average daily work of each engine-driver and fireman, expressed *in distance*. This distance, divided by the

THE LOCOMOTIVE.

average speed in miles per hour, will give the daily work on the road in time. The following are the details of this for the lines worked by the North-Western Company :—

Total mileage of engines	7,532230
Number of engine drivers and firemen	275
Annual distance worked per head	27390 miles
Daily distance worked per head	75 ,,
Time daily on the road (at the average speed of 28 miles per hour)	2 $\frac{3}{4}$ hours

If it be assumed that the engines, one with another, work on alternate days, the actual distance run in each trip by each engine on the system of lines worked by the North-Western Company will be 90 miles; which in time, at 28 miles an hour, would be $3\frac{3}{4}$ hours.

It appears, therefore, that the locomotive power is worked to greater advantage on these than on the continental lines generally. We have seen that the average distance run by each engine lighted on the Belgian lines was about 78 miles.

39. It has been customary, in some of the reports presented to the railway companies, to institute comparisons between one line of railway and another, founded upon the relation between the locomotive stock and the length of the line.

Now such a mode of comparison can afford no legitimate consequence of the least importance, either in a financial or mechanical point of view. The quantity of locomotive power does not in any manner depend on the length of the railway. The locomotive power is used to draw the traffic, and for no other purpose. Its quantity, therefore, will depend on the quantity of the traffic, and the average distance to which it is carried, or, in other words, on the mileage of the goods and passengers.

Two railways having the same traffic mileage will require the same locomotive stock, be their length equal or unequal. If a million of tons of goods require to be annually transported an average distance of 500 miles, and ten millions of passengers also require to be annually transported 300 miles, it is manifest, that the same locomotive power will be requisite to execute the traffic, whether the railway on which it is carried be 400 miles or 800 miles in length.

If the object be to compare the merits of the management of the locomotive power, then the test of comparison should be the quantity of work executed by a given quantity of this power; and the quantity of work must be decided by the useful mileage of the engines, and not by the length of the line.

Nevertheless, we find railway authorities in high repute announcing, that to stock a line requires so many engines per

LOCOMOTIVE STOCK.

mile. To such a statement there can be no objection, provided it be made with the understanding that it applies to railways only which have a certain understood amount of average traffic.

But it is clear that, with every variation of the traffic upon the proposed railway, there must be a corresponding and proportional variation in the necessary amount of locomotive stock.

40. A legitimate mode of comparing the merits of the management of the locomotive department will be found in the estimate of the average daily mileage of the engines.

It is evident, that if we find on one railway—for example, the North-Western,—the engines performing a daily mileage of 45 miles, while on another—the North of France, we find them performing a daily service under 30 miles, that the locomotive stock in the one case was more profitably managed than the other in the ratio of 2 to 3, it being understood that other things are similar. But even in this comparison it would be necessary that the length and weight of the trains should be taken into account; for if it prove that the weight of the train drawn 30 miles is greater than the weight of the train drawn 45 miles in the proportion of 3 to 2, then the useful labour of the engines will, after all, be the same. In short, the test, and the only test, of the useful effect of the locomotive power is the actual mileage (including in that term the quantity) of the traffic which it executes in a given time.

41. The conditions which determine the amount of the locomotive stock necessary to work any given railway form a very important subject of inquiry in railway economy; but it is a subject upon which we as yet possess but scanty and unsatisfactory data. As has been already stated, railway authorities have, with more rashness than skill, given a sort of rough estimate of it at so much per mile. This must, however, be regarded as utterly unworthy of attention, for the very intelligible reasons already explained.

The amount of locomotive stock depends exclusively on the mileage of the traffic. The question is thus reduced to the determination of the number of engines necessary to work a given mileage.

If we assume the results of the working of the North-Western lines as a general modulus, it would follow, that to find the quantity of stock necessary for working a given daily mileage, it will be sufficient to divide this mileage by 45; the quotient will express the requisite number of locomotive engines.

42. From calculations based upon authentic statistical returns which were published in a series of articles, written by me for the "Times," in 1851, it appeared, that in the year 1850, the gross receipts of all the European railways then in operation, amounted to 23,30900l., of which 12,75500l., or about the half, was collected on the railways of the United Kingdom.

THE LOCOMOTIVE.

Of this amount about 60 per cent has been expended on personal locomotion, and 40 per cent on the transport of goods of every denomination.

43. The movement of the locomotive engines in executing this traffic has been as follows :—

	Miles run by engines.
United Kingdom	40,162000
Germanic States	23,572000
France	10,041000
Belgium	<u>4,540000</u>
Total distance travelled by locomotive engines in 1850	78,315000

44. Since the date of these calculations, the amount of railway locomotion, as well in the United Kingdom as throughout Europe generally, has undergone a great increase. Thus, in the half year ending 30th June, 1852, the gross receipts of the railways in the United Kingdom amounted to 7,195551.

The mileage, or aggregate distance travelled by the locomotive engine, has increased in a proportion still greater than the increase of the gross receipts. Thus, while in 1850, the total annual mileage of the engines on the railways of the United Kingdom was about forty millions, in the first six months of 1852 it was twenty-eight and a half millions, being at the rate of fifty-seven millions in the year.

It may now (1854) be assumed that the aggregate annual mileage of the locomotive engines on all the European railways is not less than *an hundred and twenty millions of miles!*

45. In the performance of this work, the total quantity of coal consumed is two millions and three quarters of tons.

46. This movement is shared between passengers and goods as follows :—

Distance travelled by passenger trains	72,000000
, , , goods , ,	48,000000

Since each passenger train transported on an average 70 passengers, and each goods train 60 tons, it follows that the total locomotion of persons within the year was equivalent to 5040,000000 persons carried one mile, and the transport of goods to 2880,000000 tons transported one mile.

The number of locomotive engines employed in executing this movement was about 7500, of which 3700 were employed on the British railways, and about 5000 were constructed in England.

Fig. 5.

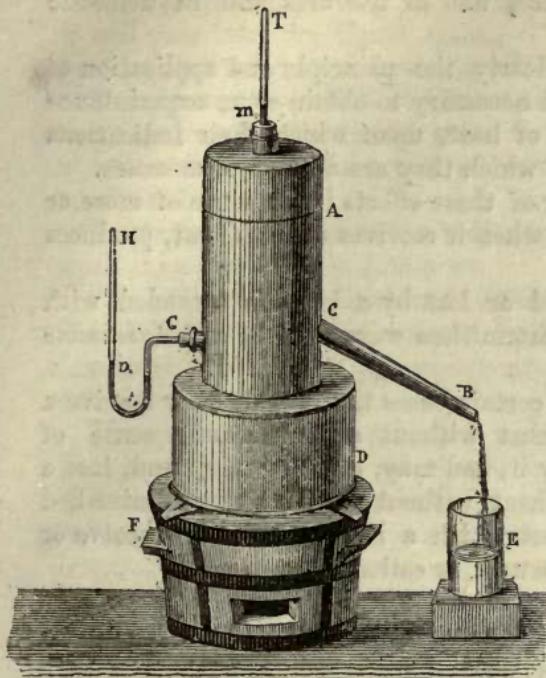
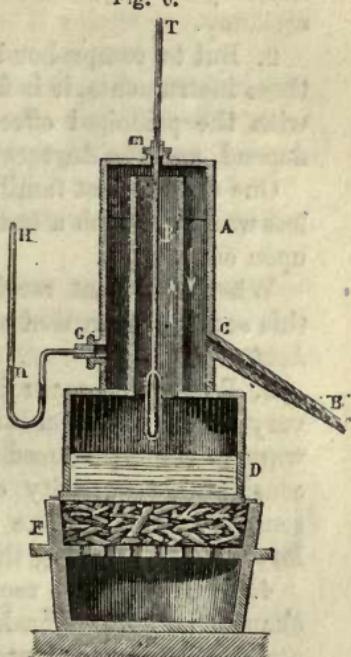


Fig. 6.



METHOD OF DETERMINING THE BOILING POINT.

THE THERMOMETER.

1. Heat.—2. Sensible heat.—3. Latent heat.—4. Contraction and dilatation.—5. Liquefaction and solidification.—6. Vaporisation and Condensation.—7. Incandescence.—8. Combustion.—9. Temperature.—10. Conduction.—11. Radiation.—12. Some bodies are pervious to heat.—13. Some reflect heat.—14. Means of measuring the degrees of heat.—15. Mercurial thermometer.—16. Preparation of mercury.—17. Selection of tube.—18. Formation of bulb.—19. How the tube is filled.—20. Scale applied.—21. Graduation of scale.—22. Zero point.—23. Standard points.—24. Freezing and boiling temperatures universally adopted.—25. Fahrenheit's scale.—26. Centigrade.—27. Reaumur's.—28. Increase of volume of mercury.—29. Uniformity of its dilatation.—30. Standard thermometer.—31. Range of scale.—32. Why mercury is employed in thermometers.—33. Self-registering thermometers.—34. Alcohol thermometers.—35. Air thermometer.—36. Differential thermometer.

1. HEAT is one of the physical agencies upon which the well-being of organised nature in general, and of the human race in particular, is most essentially dependent. The instruments, therefore, which have been contrived for indicating and measuring its quantity and degrees have great interest and importance,

THE THERMOMETER.

not only in physical science, but in the arts and in domestic economy.

2. But to comprehend clearly the principle and application of these instruments, it is first necessary to obtain some acquaintance with the principal effects of heat, upon which their indications depend, and the degrees of which they are applied to measure.

One of the most familiar of these effects 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*.

3. 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*.

4. 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 by 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 by an increase of volume.

5. 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 which are usually solid.

6. 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*.

EFFECTS OF HEAT.

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.

7. 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.

8. 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.

The phenomena of combustion and properties of combustibles have been fully explained in our Tract on "Fire."

9. 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.

THE THERMOMETER.

10. 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.

11. 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.

12. 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.

13. The surfaces of bodies also reflect heat in different

EFFECTS OF HEAT.

degrees; those rays which they do not reflect they absorb. The processes 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.

14. Of all the various effects of heat, that which is best adapted to indicate and measure temperature is 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.

Fig. 1.

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.

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.

15. The mercurial thermometer consists of a capillary * tube of glass, (fig. 1), 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. If they expanded in the same proportion, the capacity of the bulb and tube would be enlarged in the same proportion as the mercury contained in them, and, consequently, the column of mercury in the tube would neither rise nor fall, since the enlargement of its volume would be exactly equal to the enlargement of the capacity of the bulb and tube. If, however, the expansion of the bulb and tube be different from that of the mercury, the column in the tube will, after expansion, stand higher or lower than before, according as the expansion of the mercury is greater or less than the expansion of the bulb and tube.

It is found that the dilatability of mercury is greater than the



* So called from its bore being so small as not to exceed the diameter of a hair, the Latin word *CAPILLA* signifying *a hair*.

THE THERMOMETER.

dilatability of glass in the proportion of nearly 20 to 1, and, consequently, the capacity of the bulb and tube will be less enlarged than the volume of the mercury contained in them in the proportion of nearly 1 to 20; consequently, for the reason above stated, every elevation of temperature by which the mercury and tube would be affected will cause the column of mercury to rise in the tube, and every diminution of temperature will cause it to fall.

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 that proportion, the greater will be the elevation of the column produced by a given increase of temperature; for a given increase of temperature will produce a definite increase of volume in the mercury, and this increase of volume will fill a greater space in the tube in proportion to the smallness of the bore compared with the capacity of the bulb.

16. 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.

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. This object is attained by the same means as have been already explained in the case of the barometer.*

17. 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 uniformity of the bore of the tube may be tested by letting into it a small drop of mercury, sufficient to fill about a third of an inch of the tube. Let this be made to fall gradually through the entire length of the tube, stopping its motion at intervals, and

* See our Tract on "The Barometer."

FILLING THE TUBE.

let the space it occupies at different parts of the tube be measured. If this space be everywhere the same, the bore is uniform; if not, the tube must be rejected.

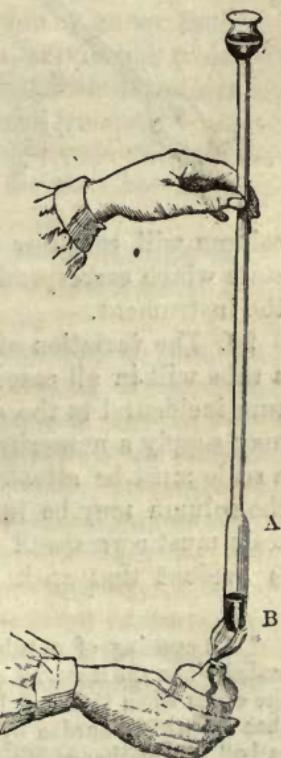
18. The bulb, whether spherical or cylindrical, can be formed upon the end of the tube by the ordinary process of glassblowing. The sensibility of the thermometer requires that the capacity of the bulb should bear a large proportion to the calibre of the tube. If, however, the capacity of the bulb be considerable, the quantity of mercury it contains may be so great that it will not be affected by the temperature of the surrounding medium with sufficient promptitude.

A cylindrical bulb of the same capacity will be more readily affected by the temperature of the surrounding medium than a spherical bulb, since it will expose a greater surface.

The glass of which the bulb is formed should be as thin as is compatible with the necessary strength, in order that the heat may pass more freely from the external medium to the mercury.

19. The tube to be filled is represented in fig. 2, where B A C is a tube, and C D a reservoir formed at the top for the purpose of filling it, which is to be afterwards detached. Let the tube be first dried by holding it over the flame of a spirit-lamp, so as to evaporate and expel all moisture which may be attached to the inner surface of the glass. To fill it, let a quantity of purified mercury be poured into the reservoir C D. This will not fall through the bore, being prevented by the air included in the reservoir A B and in the tube. To expel this, and cause the mercury to take its place, let the tube be placed in an inclined position over a charcoal fire or the flame of a spirit-lamp, so that the air shall be heated. When heated it will expand, force itself in bubbles through the mercury in C D, and escape into the atmosphere. This will continue until all the air in the bulb A B and in the tube A C has been expelled. The pressure of the atmosphere acting on the mercury in C D will then force it through the tube into the bulb A B, which, as well as the entire length of the tube, it will ultimately fill. If a sufficient quantity of mercury be supplied to the reservoir C D, the bulb A B, the tube A C, and a

Fig. 2. D



THE THERMOMETER.

part of the reservoir c d, will be filled with mercury after all the air has been expelled.

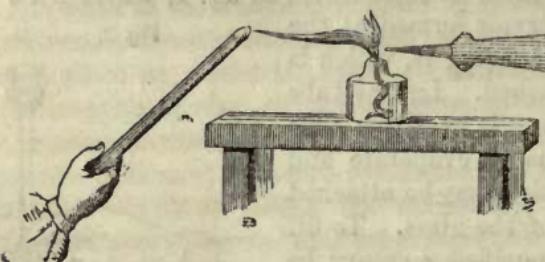
When this has been accomplished, let the tube be removed from the source of heat, and allowed gradually to cool. A file applied at c, where the top of the tube is joined to the superior reservoir, detaches that reservoir from the tube, which remains with the bulb a b completely filled with mercury.

In this state the instrument would give no indication of change of temperature, no space being left for exhibiting the play of the mercury by dilatation and contraction.

To obtain space for this, let the bulb a b be exposed to a temperature higher than any which the instrument is intended to indicate. The mercury dilating will then overflow, and will continue to overflow until the mercury acquires the extreme temperature to which it is exposed.

A jet of flame being now directed by a blow-pipe (fig. 3), on

Fig. 3.



the end c, it will be hermetically* sealed; after which, being allowed to cool, the mercurial column will subside, the space in the tube above it being a vacuum, since the air is expelled. The

column will continue to subside until the mercury assumes that state which corresponds to the temperature of the air surrounding the instrument.

20. The variation of the height of the mercurial column in such a tube will in all cases correspond with the changes of temperature incidental to the surrounding medium; but, in order that it may supply a numerical expression and measure of such changes, a scale must be attached to the tube, by which the variations of the column may be indicated, and the divisions or units of such scale must correspond to some known change of temperature. It is evident that such a scale, like all other standards for the

* An opening of a tube or vessel is said to be hermetically closed or sealed when the material of the tube or vessel itself is fused around it, and the edges when thus soft brought together so as to close the opening, being then allowed to harden by cold as sealing-wax does. The term "hermetically" means chemically, the science of alchemy which preceded chemistry being supposed to have been invented by Hermes Trismegistus. So that "hermetically sealed or closed" means to be sealed or closed in the manner adopted in chemical vessels.

STANDARD POINTS.

arithmetical measure of physical effects, must be to some extent arbitrary. We accordingly find different scales and different thermometric units prevailing in different countries, and even in the same country at different times.

21. Whatever thermometric unit be adopted, it is necessary that two standard temperatures be selected, to which the mercury can be reduced at the times and places where thermometers may be required to be constructed or verified. The instrument being exposed to these two temperatures, the points at which the mercurial column stands are marked upon the scale. The space upon the scale between these points is then divided into a certain number of equal parts, which are called degrees, the degree being the thermometric unit. The same divisions are then continued upon the scale above the higher and below the lower standard point, and such divisions may be continued indefinitely. The scale is then complete.

In this process, the number of equal parts into which the space between the standard points is divided, is altogether arbitrary.

22. It now remains to number the scale; and, for this purpose, a zero point must be selected. If there existed a minor limit to temperature, a temperature below which no body could possibly fall, then such a temperature would supply a natural thermometric zero, and the scale might be numbered upwards from it.

In that case, although the thermometric unit would still remain arbitrary, the zero of the scale would not be so. But no such natural thermometric zero exists.

There is no natural limit either to the increase or diminution of temperature. The zero, therefore, of the thermometric scale, like the thermometric scale itself, must be arbitrary.

23. Thermal phenomena present great varieties of standard temperatures, by which thermometric scales may be established, and which may serve equally as terms of temperature for the purpose of distinguishing the indications of different thermometers constructed at different times and places. Thus, the temperatures at which all solid bodies fuse, and those at which all liquids congeal, are fixed. For different bodies these are different, but always the same for the same body. In like manner, the temperatures at which all liquids boil under a given pressure are invariable for the same liquids, though different for different liquids. The temperature of the blood in the human species presents another example of a fixed temperature.

24. Now, any two of these various temperatures naturally fixed might be taken as the thermometric standards, the choice being altogether arbitrary. Thus, it appears that the arithmetical division of the scale, and consequently the thermometric unit, the

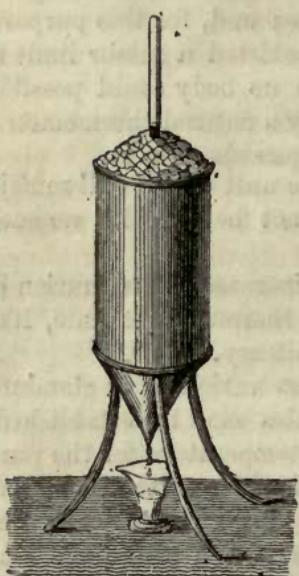
THE THERMOMETER.

position of its zero, and, in fine, the standard temperatures by which alone the indication of different thermometers can be rendered comparable, are severally arbitrary. Unanimity, nevertheless, has prevailed in the selection of standard temperatures. The temperature at which ice melts, and that at which distilled water boils, when the barometer stands at 29.8 inches, have been adopted in all countries as the two temperatures with reference to which thermometric scales are constructed.

The bulb and tube, as already described, being filled with pure mercury, and a blank scale being attached to the tube, the instrument is immersed successively in melting ice and boiling water, and the points at which the mercurial column stands in each case are marked upon the scale. The former is called the FREEZING-POINT, and the latter the BOILING-POINT.

The apparatus by which the freezing point is determined is shown in fig. 4. The thermometer is immersed nearly to the level of the mercury in a vessel of pounded ice, which being in a state of fusion, the water proceeding from it discharged through a funnel in the bottom is received in a vessel placed under it.

Fig. 4.



The apparatus for determining the boiling point is shown in fig. 5, where D is the boiler, placed over a charcoal furnace, the whole being shown in section in fig. 6, p. 145. From the top of the boiler a tube proceeds, open at the top, which is enveloped in another larger one, A, closed at the top, and soldered at the bottom to the top of the boiler. In the external tube A, there are three openings, in one of which, m, the tube of the thermometer T is inserted. In another, a siphon mercurial gauge G H, and in the third a discharge pipe c b, is inserted. When the water boils the steam rises, surrounding the bulb and tube, and descending between the two tubes, issues from the discharge pipe b.

If the steam be generated too rapidly in the boiler, it will press on the mercury in the gauge, which will then stand at a higher level, n, in the ascending than in the descending leg. The pressure of the steam will be in that case greater than that of the atmosphere, and the force of the furnace must be moderated until the levels of the mercury in the two legs of the siphon-

DIFFERENT SCALES.

coincide. In that case the pressure of the steam will be exactly equal to that of the atmosphere.

25. The same unanimity has not prevailed either as respects the unit or the thermometric zero. In England, Holland, some of the German States, and in North America, the interval between the freezing and boiling points is divided into 180 equal parts, each part representing the thermometric unit. The scale is continued by equal divisions above the boiling and below the freezing points.

The zero is placed at the thirty-second division below the freezing point; so that, on this scale, the freezing point is 32° , and the boiling point $32^{\circ} + 180^{\circ} = 212^{\circ}$.

This scale is known as Fahrenheit's, and was adopted about 1724.

The reason for fixing the zero of the scale at 32° below the freezing point is, that that point indicated a temperature which was at that time believed to be the natural zero of temperature, or the greatest degree of cold that could exist, being the most intense cold which had been observed in Iceland.

We shall see hereafter that much lower temperatures, natural and artificial, have been since observed.

The division of the interval between the freezing and boiling points into 180 equal parts was founded upon some inexact supposition connected with the dilatation of mercury.

The divisions of this scale are continued in the same manner below zero, such divisions being considered negative, and expressed by the negative sign prefixed to them. Thus, $+ 32^{\circ}$ signifies 32° above zero, but $- 32^{\circ}$ signifies 32° below zero.

26. In France, Sweden, and some other parts of Europe, the Centigrade scale prevails.

In this scale the interval between the freezing and boiling points is divided into 100 equal parts, and the zero is placed at the freezing point.

27. In some countries the scale of Reaumur is used, in which the interval between the freezing and boiling points is divided into eighty equal parts, the zero being placed at the freezing point.

28. It has been ascertained by experiment, that mercury, when raised from 32° to 212° , suffers an increment of volume amounting to $2\frac{1}{11}$ ths of its volume at 32° . Thus, 111 cubic inches of mercury at 32° will, if raised to 212° , become 113 cubic inches. From this may be deduced the increment of volume which mercury receives for each degree of temperature. For, since the increase of volume corresponding to an elevation of 180° is $\frac{2}{11}$ of its volume at 32° , we shall find the increment of volume corresponding to one degree by dividing $\frac{2}{11}$ by 180, or, what is the

THE THERMOMETER.

same, by dividing $\frac{1}{1}$ by 90, which gives $\frac{1}{990}$. For each degree of temperature by which the mercury is raised, it will therefore receive an increment of volume amounting to the 9990th part of its volume at 32° , and it follows, that the weight of mercury which fills the portion of a thermometric tube representing one degree of temperature, will be the 9990th part of the total weight contained in the bulb and tube.

29. In adopting the dilatation of mercury as a measure of temperature, it is assumed that equal dilatations of this fluid are produced by equal increments of heat. Now, although it is certain that to raise a given quantity of mercury from the freezing to the boiling point will always require the same quantity of heat, it does not follow that equal increments of volume will correspond to equal increments of heat throughout the whole extent of the thermometric scale. Thus, although the same quantity of heat must always be imparted to the mercury contained in the tube to raise it from 32° to 212° , it may happen that more or less heat may be required to raise it from 32° to 42° , than from 202° to 212° . In other words, the dilatation produced by equal increments of heat, in different parts of the scale, might be variable. Experiments conducted, however, under all the conditions necessary to ensure accurate results, have proved that mercury is uniformly dilated between the freezing and boiling points, or that equal increments of heat imparted to it produce equal increments of volume.

30. A thermometer having once been carefully graduated may be used as a standard instrument for graduating other thermometers, just as good chronometers once accurately set are used as regulators for other time-pieces. To graduate a thermometer by means of such a standard, it is only necessary to expose the two instruments to the same varying temperatures, and to mark upon the blank scale of that which is to be graduated two points corresponding to any two temperatures shown by the standard thermometer, and then to divide the scale accordingly.

Thus, for example, if the two instruments be immersed in warm water and the column of the standard thermometer be observed to indicate the temperature of 150° , let the point at which the mercury stands in the other thermometer be marked 150 upon its scale.

Let the two instruments be then immersed in cold water and let us suppose that the standard thermometer indicates 50° . Let the point at which the instrument to be graduated stands be then marked. Let the intervals of the scale between these two points, thus corresponding to the temperatures of 50° and 150° , be divided into one hundred equal parts; each part will be a degree

STANDARD THERMOMETER.

in the scale, which may be continued by like divisions above 150° and below 50° .

31. The range of the scale of thermometers is determined by the purpose to which they are to be applied. Thus, thermometers intended to indicate the temperature of dwelling-houses need not range above or below the extreme temperatures of the air, and the scale does not usually extend much below the freezing point nor above 100° ; and thus the sensitiveness of the instrument may be increased, since a considerable length of the tube may represent a limited range of the scale.

32. Mercury possesses several thermal qualities which render it a convenient fluid for common thermometers. It is highly sensitive to change of temperature, dilating with promptitude by the same increments of heat with great regularity and through a considerable range of temperature. It will be shown hereafter that a smaller quantity of heat produces in it a greater dilatation than in most other liquids. It freezes at a very low and boils at a very high temperature. At the temperatures which are not near these extreme limits, it expands and contracts with considerable uniformity.

The freezing point of mercury being — 40° , or 40° below zero, and its boiling point + 600° , such a thermometer will have correct indications through a very large range of temperature.

33. It is sometimes needed, in the absence of an observer, to ascertain the variations which may have taken place in a thermometer. Instruments called self-registering thermometers have been contrived, which partially serve this purpose by indicating, not the variations of the mercurial column, but the limits of its play within a given time. This is accomplished by floating indices placed on the mercury within the tube, which are so adapted that one is capable of being raised with the column, but not depressed, and the other of being depressed, but not raised. The consequence is, that one of these indices will remain at the highest, and the other at the lowest point which the mercurial column may have attained in the interval, and thus register the highest point and lowest point of its range.

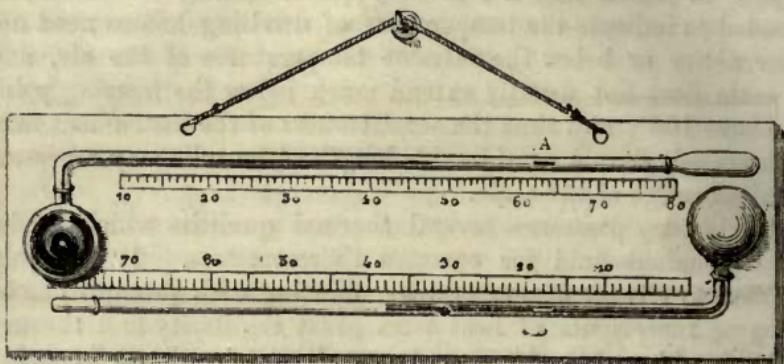
One of the most common and useful forms of self-registering thermometer is that of Rutherford, shown in fig. 7, which consists of two tubes, attached in a horizontal position to a plate of glass, being bent at right angles near the bulbs; one, A, containing mercury and the other, B, alcohol. In the tube of the former there is a small piece of iron wire, which moves in it freely, being pushed along by the mercury as it expands. When the tube is placed in the vertical position the wire falls back upon the mercury.

The other tube contains a small piece of coloured glass, having

THE THERMOMETER.

a knob at each end, which allows the alcohol to pass it freely from right to left. But when the alcohol contracts and moves

Fig. 7.



towards the bulb, it carries with it the glass index, which consequently remains in the position given to it when exposed to the lowest temperature.

The instrument, therefore, after the lapse of any time, indicates the highest and lowest temperatures to which it has been exposed. A small magnet is sometimes attached, to aid in bringing the wire gently into contact again with the mercury, and in cheap instruments, especially in England, the scale is engraved on a slab of wood instead of a plate of glass.

A maximum and minimum thermometer has lately been introduced by Messrs. Negretti and Zambra, which is a modification of the above. Having introduced into the tube a little rod of glass, the tube is softened with the blow-pipe, and slightly bent where the glass rod stands, so that it becomes fixed in the tube, leaving nevertheless sufficient space around it for the mercury to pass. Supposing, then, the instrument to be suspended with the tube horizontal, and exposed to an increasing temperature, the mercury passes the bend; but when the temperature falls, the mercury which has just passed will not return. The extremity of the column will therefore indicate the highest temperature to which the instrument has been exposed. This instrument is represented in fig. 8.

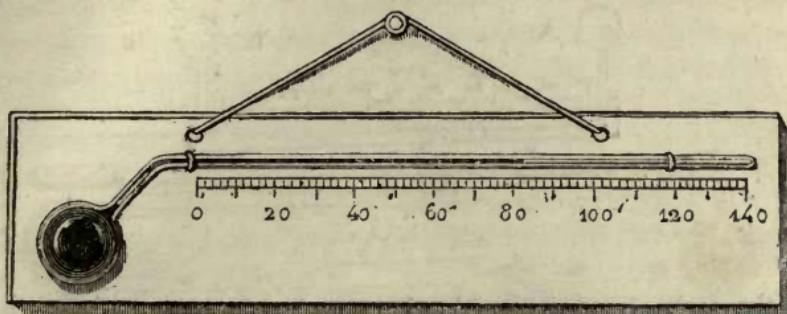
34. Alcohol is frequently used as a thermoscopic liquid. It has the advantage of being applicable to a range of temperature below the freezing point of mercury; no degree of cold yet observed in nature or attained by artificial processes having frozen it. It is usually coloured so as to render the column easily observable in the tube.

35. Atmospheric air is a good thermoscopic fluid. It has the

DIFFERENTIAL THERMOMETERS.

advantage over liquids in retaining its gaseous state at all temperatures, and in the perfect uniformity of its dilatation and

Fig. 8.



contraction. It is also highly sensitive, indicating changes of temperature with great promptitude. Since, however, it is not visible, its expansion and contraction must be rendered observable by expedients which interfere with and render complicated its indications.

The air thermometer of Drebzel, or according to some of Sanctorius, is represented in fig. 9. A glass tube, A B, open at one end, and having a large thin bulb c at the other, is placed with its open end in a coloured liquid, so that the air contained in the tube shall have a less pressure than the atmosphere. A column of the liquid will therefore be sustained in the tube A B, the weight of which will represent the difference between the pressure of the external air and the air inclosed in the tube.

If the bulb c be exposed to a varying temperature, the air included in it will expand and contract, and will cause the column of coloured liquid in the tube A B to rise and fall, thereby indicating the changes of temperature.

Fig. 10. Another form of air thermometer is represented in fig. 10. The air included fills half the capacity of the bulb c, and its expansion and contraction cause the coloured liquid to rise or fall in the tube A B.

36. Of all forms of air thermometer, that which has proved of greatest use in physical enquiries is the differential thermometer represented in figs. 11, 12. This consists of two glass bulbs, A and B, connected by a rectangular glass tube. In the horizontal part of the tube a small quantity of coloured liquid (sulphuric acid, for example) is placed. Atmospheric air is contained in the bulbs and tube, separated into two parts by the

Fig. 9.

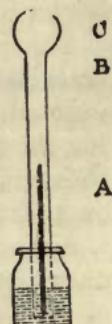
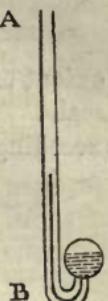


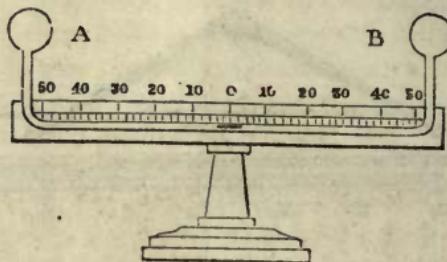
Fig. 10.



THE THERMOMETER.

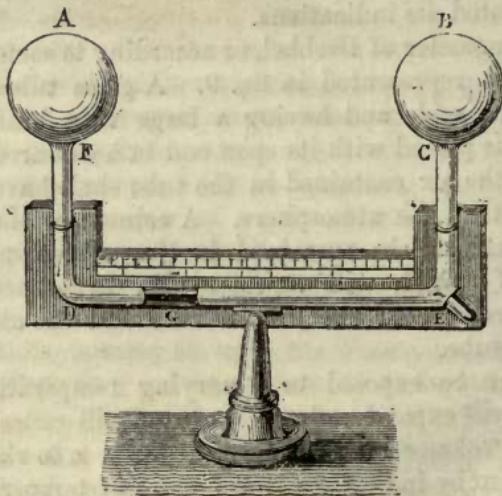
liquid. The instrument is so adjusted that, when the drop of liquid is at the middle of the horizontal tube, the air in the bulbs

Fig. 11.



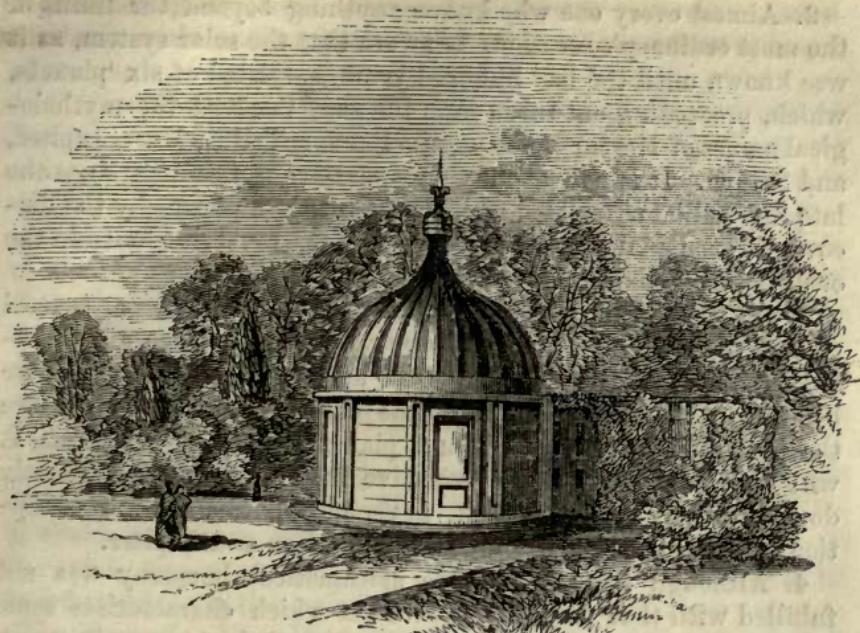
has the same pressure; and having equal volumes, the quantities at each side of the liquid are necessarily equal. If the bulbs be affected by different temperatures, the liquid will be driven from

Fig. 12.



that side at which the temperature is greatest, and the extent of its departure from the zero or middle is indicated by the scale.

By these instruments changes of temperature, not exceeding the 6000th part of a degree, are rendered sensible.



MR. BISHOP'S OBSERVATORY, REGENT'S PARK, MEMORABLE BY THE DISCOVERY
THERE OF ELEVEN PLANETS.

THE NEW PLANETS.

- 1.—Discovery of these planets.—2. The old planets.—3. Numerical law of their distances.—4. A missing planet.—5. Conjecture of Professor Bode.—6. Discovery of Ceres.—7. Of Pallas.—8. Theory of Dr. Olbers—a broken planet.—9. Discovery of Juno.—10. Of Vesta.—11. Rapid discovery of the others.—12. Table of the group.—13. Circumstances corroborating the theory of Dr. Olbers.—14. Amateur astronomers.—15. Minute bulk of these planets.—16. Corroboratory of Dr. Olbers' theory.—17. Force of gravity upon them.

1. WITHOUT being astronomers, every one who reads the newspapers must be familiar with the fact, that within the last few years a multitude of small planets has been discovered, which, notwithstanding the vigilance and sagacity of observers, in various parts of Europe, had hitherto escaped notice. As the circumstances attending and preceding this extraordinary mass of astronomical discovery are novel and interesting, we propose at present to bring them before our readers.

THE NEW PLANETS.

2. Almost every one who knows anything beyond the limits of the most ordinary education, is aware that the solar system, as it was known until the last hundred years, consisted of six planets, which, proceeding outwards from the sun, received the mythological names of Mercury, Venus, the Earth or Tellus, Mars, Jupiter, and Saturn. It is now about three-quarters of a century since the late Sir William Herschel added one to this number, by the discovery of the planet since called Uranus, revolving outside the orbit of Saturn.

3. On comparing the successive distances of these several planets from the sun, it was observed by Kepler, that a remarkable numerical harmony prevailed among them. Thus, if we begin from the nearest planet to the sun, Mercury, and measure the intervals between planet and planet proceeding outwards, it will be found that each successive interval is almost exactly double the one before, subject, nevertheless, to a striking exception in the case of the interval between Mars and Jupiter.

4. Although this remarkable arithmetical harmony was not fulfilled with that numerical precision which characterises some other astronomical laws, there was, nevertheless, so striking an approximation to it as to produce a strong impression, that it must be founded upon some physical cause, and not merely accidental. The near approximation to its exact fulfilment, supplied grounds for a very reasonable conjecture, that a planet was wanting in the system, whose position between Mars and Jupiter would be such as to fill the vacant place in the progression of distances.

To show how strong the analogy was in favour of such a supposition, we have placed in the following table the succession of calculated distances from Mercury's orbit, which will exactly fulfil it, in juxtaposition with the actual distances of the planets, the earth's distance from the sun being the unit.

	Calculated distance from Mercury.	Actual distance from Mercury.
Venus	0.3362	0.3362
Earth	0.6724	0.6129
Mars	1.3448	1.1366
Absent planet	2.6896	
Jupiter	5.3792	4.8157
Saturn	10.7584	9.1517
Uranus	21.5168	18.7953

By comparing these numbers, it will be apparent, that although the succession of distances does not correspond precisely with a.

numerical series in duple progression, there is nevertheless a certain approach to such a series, and at all events a glaring breach of continuity between Mars and Jupiter.

5. Towards the close of the last century, Professor Bode, of Berlin, revived this question of a deficient planet, and gave the numerical progression which indicated its absence in the form in which it has just been stated; and an association of astronomers was formed under the auspices of the celebrated Baron de Zach, of Gotha, to organise and prosecute a course of observation, with the special purpose of searching for the supposed undiscovered member of the solar system. The very remarkable results which have followed this measure, the consequences of which have not even yet been fully developed, will presently be apparent.

6. On the first day of the present century, Professor Piazzi observing in the fine serene sky of Palermo, noticed a small star of about the 7th or 8th magnitude which was not registered in the catalogues. On the night of the 2nd Jan. again observing it, he found that its position relative to the surrounding stars was sensibly changed. The object appearing to be invested with a nebulous haze, he took it at first for a comet, and announced it as such to the scientific world. Its orbit being, however, computed by Professor Gauss, of Göttingen, it was found to have a period of 1652 days, and a mean distance from the sun expressed by 2.735, that of the earth being 1.

By comparing this distance with that given in the preceding table at which a planet was presumed to be absent, it will be seen that the object thus discovered filled the place with striking arithmetical precision.

Piazzi gave to this new member of the system the name CERES.

7. Soon after the discovery of Ceres, the planet passing into conjunction ceased to be visible. In searching for it after emerging from the sun's rays in March, 1802, Dr. Olbers noticed on the 28th a small star in the constellation of Virgo, at a place which he had examined in the two preceding months, and where he knew that no such object was *then* apparent. It appeared as a star of the seventh magnitude, the smallest which is visible without a telescope. In the course of a few hours he found its position visibly changed in relation to the surrounding stars. In fine, the object proved to be another planet, bearing a striking analogy to Ceres, and what was then totally unprecedented in the system, moving in an orbit at very nearly the same mean distance from the sun, and having, therefore, nearly the same period.

THE NEW PLANETS.

Dr. Olbers called this planet PALLAS.

8. This circumstance, combined with the exceptional minuteness of these two planets, suggested to Olbers the startling, and then, as it must have appeared, extravagantly improbable hypothesis, that a single planet of the ordinary magnitude existed formerly at the distance indicated by Bode's analogy,—that it was broken into small fragments either by internal explosion from some cause analogous to volcanic action, or by collision with a comet,—that Ceres and Pallas were two of its fragments, and in fine, that it was very likely that many other fragments, smaller still, were revolving in similar orbits, many of which might reward the labour of future observers who might direct their attention to these regions of the firmament.

In support of this curious conjecture, it was urged that in the case of such a catastrophe as was involved in the supposition, the fragments, according to the established laws of physics, would necessarily continue to revolve in orbits, not differing much in their mean distances from that of the original planet; that the obliquities of the orbits to each other and to that of the original planet might be subject to a wider limit; that the eccentricities might also have exceptional magnitudes; and, finally, that such bodies might be expected to have magnitudes so indefinitely minute as to be out of all analogy or comparison, not only with the other primary planets, but even with the smallest of the secondary ones.

Ceres and Pallas were both so small as to elude all attempts to estimate their diameters, real or apparent. They appeared like stellar points with no appreciable disk, but surrounded with a nebulous haziness, which would have rendered very uncertain any measurement of an object so minute. Sir W. Herschel thought that Pallas did not exceed 75 miles in diameter. Others have admitted that it might measure a few hundred miles. Ceres is still smaller.

The obliquity of the orbit of Ceres to the plane of the ecliptic is above $10\frac{1}{2}^{\circ}$, and that of Pallas more than $34\frac{1}{2}^{\circ}$. Both planets, therefore, when most remote from the ecliptic pass far beyond the limits of the zodiac, and differ in obliquity from each other by a quantity far exceeding the entire inclination of any of the older planets.

It was further observed by Dr. Olbers, that at a point near the descending node of Pallas, the orbits of the two planets very nearly coincided.

Thus it appeared that all the conditions which rendered these bodies exceptional, and in which they differed from the other members of the solar system, were precisely those which were

DISCOVERY OF JUNO AND VESTA.

consistent with the hypothesis of their origin advanced by Dr. Olbers.

9. A year and a half elapsed before any further discovery was produced to favour this hypothesis. Meanwhile, observers did not relax their zeal and their labours, and on Sept. 1, 1804, at ten o'clock, P.M., Professor Harding, of Lilienthal, discovered another minute planet, which observation soon proved to agree in all its essential conditions with the hypothesis of Olbers, having a mean distance very nearly equal to those of Ceres and Pallas, an exceptional obliquity of 13° , and a considerable eccentricity.

This planet was named JUNO.

Juno has the appearance of a star of the 8th magnitude, and a reddish colour. It was discovered with a very ordinary telescope, of 30 inches focal length and 2 inches aperture.

10. On the 29th of March, 1807, Dr. Olbers discovered another planet, under circumstances precisely similar to those already related in the cases of the former discoveries. The name VESTA was given to this planet, which, in its minute magnitude, and the character of its orbit, was analogous to Ceres, Pallas, and Juno.

Vesta is the brightest, and, apparently, the largest of all this group of planets; and, when in opposition, may be sometimes distinguished by good and practised eyes without a telescope. Observers differ in their impressions of the colour of this planet. Harding and other German observers consider her to be reddish; others contend that she is perfectly white. Mr. Hind says that he has repeatedly examined her under various powers, and always received the impression of a pale yellowish cast in her light.

11. The labours of the observers of the beginning of the century having been now prosecuted for some years without further results, were discontinued; and it is probable that but for the admirable charts of the stars which have been since published, no other members of this remarkable group of planets would have been discovered. These, however, containing all the stars up to the 9th or 10th magnitude, included within a zone of the firmament 30° in width, extending to 15° on each side of the celestial equator, supplied so important and obvious an instrument of research, that the subject was again resumed, with a better prospect of successful results. It was only necessary for the observer, map in hand, to examine, degree by degree, the zone within which such bodies are known to move, and to compare, star by star, the heavens with the map. When a star is observed which is not marked on the map, it is watched from hour to hour, and from night to night. If it do not change its position, it must be inferred that it has been omitted in the construction of the map, and it is marked upon it

THE NEW PLANETS.

in its proper place. If it change its position, it must be inferred to be a planet, and its orbit is soon calculated from its observed changes of position.

By these means M. Hencke, an amateur observer of Driesen in Prussia, discovered, on the 8th December, 1845, another of the small planets, which has been named *ASTREA*.

This discovery was the signal for an extraordinary start. It had so happened that within some years several private observatories had been established, and a most respectable, intelligent, and wealthy body of amateurs and volunteers has been added to the regular professional astronomical corps. The result of this is, that within a few years a most unexpected number of planets has been discovered, all occupying nearly the same place in the system; thus, three were discovered in 1847, one in 1848, one in 1849, three in 1850, two in 1851, eight in 1852, four in 1853, and six in 1854, and one on the 6th April, 1855,—making the total number discovered to the date of writing these lines (1st May, 1855) thirty-four.

12. A tabular statement of the elements of these planets was published in the “*Annuaire du Bureau des Longitudes*” at Paris for the present year, 1855, by M. Le Verrier and his assistants. Recently, however, a much more complete table has been published by Mr. Bishop, whose observatory in the Regent’s Park has been signalised by the discovery of eleven of these thirty-four bodies. Desiring to give as wide circulation as possible to this mass of interesting astronomical data, I would refer the reader to Mr. Bishop’s table, from which I have extracted the one annexed to this notice.

To facilitate such researches, Mr. Bishop and his assistants commenced in the winter of 1846-7 the preparation of a series of charts, including all stars to those of the eleventh magnitude, within 3° of the ecliptic. “At the present moment,” says Mr. Bishop, writing in March, 1855, “fourteen maps are finished, engraved, and published to assist other observers in their search for new planetary bodies, and it is hoped to place the others before the public with no great delay.” It was in the preparation of these charts, aided by those of Berlin, that ten planets were discovered at Mr. Bishop’s observatory by Mr. Hind, and the eleventh more recently by Mr. Marth.

Mr. Bishop remarks, that during the preparation of his maps several other planets were seen, but lost again through the long-continuance of unfavourable weather, or owing to the object not having been missed at a sufficiently early period after it was entered upon the map.

Too much credit cannot be given to various astronomers,

ZODIACAL STELLAR CHARTS.

amateur as well as professional, for the spirit and perseverance with which they have undertaken the preparation of these Zodiacal Stellar Charts. Mr. Cooper of Sligo, and his assistant Mr. Graham, are understood to be thus occupied. They have already published three volumes containing the approximate positions of more than 45000 stars. Professor De Gasparis, of Naples, and Mr. Chacornac, of Paris, are similarly engaged.

In further illustration of the table annexed to this notice, Mr. Bishop adds the following observations :—

The *fourth* column contains the estimated magnitude or degree of brightness of each planet at the time of discovery. It would appear that the four which attain the highest degree of brilliancy are Vesta (often visible without a telescope), Pallas, Iris, and Flora.

The *fifth* column gives the mean longitude for noon, Greenwich time, on the 1st of January, 1855, reckoned from the equinox of that date.

In the *sixth* is found the longitude of the perihelion, or nearest point of approach of each planet to the sun, as viewed from that luminary.

The *seventh* contains the position of the ascending node, or the point in the ecliptic where the planet passes from south to north latitude, as viewed from the sun.

The *eighth* shows the inclination of each orbit to the ecliptic, or the angle between the planes of the paths of the earth and planet. It will be remarked that Pallas, Euphrosyne, and Phoebe, have the largest inclinations, while Massilia and Themis exhibit the least ; or, in other words, revolve nearly in the ecliptic.

The *ninth* column expresses the amount of eccentricity or deviation from the circle. It varies from 0.075 in the case of Amphitrite to 0.346 in that of Polyhymnia.

The *tenth* gives the mean daily sidereal motion, or the space through which each planet would move in one day, if it described a circle round the sun with its average velocity. The numbers in this column multiplied by the periods expressed in days will, therefore, be equal to the circumference, or 360°.

The *eleventh* shows the mean distances from the sun, or the semi-axes major of the orbits, expressed in units of the earth's average distance from that body, and carried to two places of decimals. Flora has the least, and, according to the table, Euphrosyne the greatest ; though the recent date of this planet's discovery, and consequent comparatively short extent of observation, leaves us in a little uncertainty whether its mean distance will ultimately be found to exceed that of Hygeia or Themis.

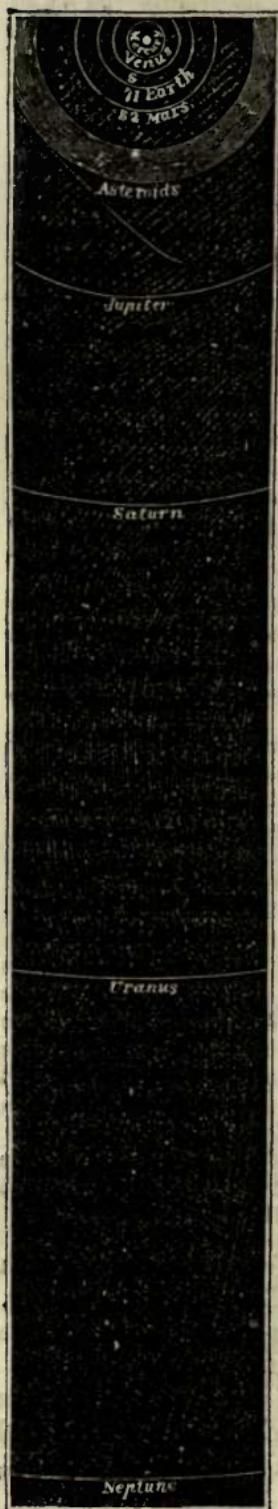
The *twelfth* shows the length of the sidereal revolution in days. The periods vary from 1193 days, that of Flora, to 2048 days, which is that of Euphrosyne ; the difference amounting to 855 days, or $2\frac{1}{3}$ years.

I have annexed to the table the thirty-fourth and thirty-fifth planets discovered by Mr. Chacornac and M. Luther since Mr. Bishop's table was printed. The elements of the last of these objects, however, have not yet been determined.

13. In their exceptional minuteness of volume, their mean distances from the sun, and the very variable obliquities and eccentricities of their orbits, they all resemble the first four dis-

THE NEW PLANETS.

Fig. 1.



covered in the beginning of the century, and are therefore in complete accordance with the conditions mentioned in the curious hypothesis of Olbers above stated.

The planet discovered by M. Gasparis, on the 17th of March, 1852, was observed by that astronomer at the Naples Observatory, on the 17th, 19th, and 20th March. It appeared as a star of the 10th or 11th magnitude. The observations were published in the "Comptes Rendus," of the Academy of Sciences, Paris, tome xxxiv. p. 532.

The planet discovered by M. Luther was observed by that astronomer at Bilk, near Dusseldorf, on the 17th April, and again by M. Argelander, on the 22d April, at Bonn. The observations were published in the "Comptes Rendus" of the Paris Academy, tome xxxiv. p. 647.

14. Dr. Olbers was a practitioner in medicine, Messrs. Hencke, Luther, and Goldschmidt amateur observers, Mr. Hind has been engaged in the private observatory of Mr. Bishop, in the Regent's Park, and Mr. Graham in that of Mr. Cooper, at Markree, in the county of Sligo, in Ireland. It appears, therefore, that of these twenty-three members of the solar system the scientific world owes no less than fourteen to amateur astronomers, and observatories erected and maintained by private individuals, totally unconnected with any national or public establishments, and receiving no aid or support from the state. Mr. Hind has obtained for himself the honourable distinction which must attach to the discoverer of ten of these bodies. Five are due to M. de Gasparis, assistant-astronomer at the Royal Observatory at Naples.

M. Hermann Goldschmidt is an historical painter, a native of Frankfort-on-the-Maine, but resident for the last eighteen years in Paris. He discovered the planet with a small ordinary telescope, placed in

TOTAL NUMBER DISCOVERED.

the balcony of his apartment, No. 12, Rue de Seine, in the Faubourg St. Germain.

15. By inspecting the above table, it will be seen that these thirty-three planets move within a region of the solar system comprised between 2·2 and 3·2 times the mean distance of the earth. Their magnitudes are too minute to be ascertained with any degree of precision and certainty by any means of measurement hitherto discovered, and it may be inferred, with great probability, that they do not in general exceed 100 miles, that is, the 80th part of the diameter of the earth. Assuming, then, such to be their mean dimensions, and considering that the bulk of globes is in the proportion of the cubes of their diameters, it would follow, that, to make a globe as large as the earth, it would be necessary that 512000 such planets as these should be rolled into one.

16. It will not fail to be observed, what great probability this extreme minuteness of bulk, combined with the circumstance of their being all so nearly at the same distance from the sun, gives to the hypothesis of Dr. Olbers.

To show the relative position of this group of planets and those of the larger members of the system, we have represented in fig. 1, in their proper proportions, the successive distances of the planets from the sun, the place of these new planets being indicated by the band of parallel circles drawn in close proximity.

Being distinguished from the other planets of the system by so many singular circumstances, some astronomers denominated these bodies Asteroids; we think, however, that, for reasons that must be obvious, the name Planetoids would be preferable.

17. From the minuteness of their masses, the force of gravity on the surface of these bodies must be very inconsiderable; and this would account for a circumstance which has been observed on some of them, namely, that their atmospheres are relatively much more extensive than those of the larger planets, since the same mass of air, feebly attracted, would dilate into a volume comparatively enormous. Muscular power would be more efficacious on them in the same proportion; thus, a man might spring upwards through sixty or eighty perpendicular feet, and return to the ground, sustaining no greater shock than would be felt upon the earth in descending from the height of two or three feet. "On such planets," observes Herschel, "giants might exist, and those enormous animals which on earth require the buoyant power of water to counteract their weight."

THE NEW PLANETS.

Name of Planet.	Date of discovery.	Discoverer.	Magnitude.	Mean Longitude, 1855, Jan. 1, at noon.	Longitude of Perihelion.	Long. of ascending node.	Inclination of orbit to the Ecliptic.	Eccentricity.	Mean daily sidereal motion.	Mean distance from the Sun (Earth's as unity).	Sidereal revolution in days.
	18		° ° °	° ° °	° ° °	° ° °	° ° °	/ "			
Ceres	01 Jan.	Piazzi	8 340	150	81 11	0°08	12 51 2°77	1680			
Pallas	02 Mar.	Olbers	7 319	122	173 35	0°24	12 49 2°77	1686			
Juno	04 Sept.	Harding	8 210	54	171 13	0°26	13 34 2°67	1592			
Vesta	07 Mar.	Olbers	7 250	251	103 .7	0°09	16 17 2°36	1326			
Astraea ...	45 Dec.	Hencke	9 157	136	142 5	0°19	14 18 2°58	1511			
Hebe	47 July	Hencke	9 283	15	139 15	0°20	15 39 2°43	1380			
Iris	47 Aug.	Hind	9 336	41	260 5	0°23	16 32 2°39	1346			
Flora	47 Oct.	Hind	9 121	33	110 6	0°16	18 6 2°20	1193			
Metis	48 Apr.	Graham	10 147	72	69 6	0°12	16 2 2°39	1347			
Hygeia ...	49 Apr.	Gasparis	9 207	228	288 4	0°10	10 35 3°15	2041			
Parthenope	50 May	Gasparis	9 317	317	125 5	0°10	15 24 2°45	1402			
Victoria ...	50 Sept.	Hind	8 51	302	236 8	0°22	16 35 2°33	1300			
Egeria	50 Nov.	Gasparis	9 46	120	43 17	0°09	14 17 2°58	1512			
Irene	{ 51 May	Hind									
	,, May	Gasparis	9 178	179	87 9	0°17	14 14 2°59	1518			
Eunomia ...	51 July	Gasparis	9 234	28	294 12	0°19	13 46 2°64	1570			
Psyche.....	52 Mar.	Gasparis	10 347	13	151 3	0°13	11 50 2°92	1825			
Thetis	52 Apr.	Luther	10 94	259	125 6	0°13	15 12 2°47	1421			
Melpomene	52 June	Hind	9 199	15	150 10	0°22	17 0 2°30	1271			
Fortuna ...	52 Aug.	Hind	9 209	31	211 2	0°16	15 29 2°44	1395			
Massilia ...	{ 52 Sept.	Gasparis	9 237	98	207 1	0°15	15 50 2°41	1364			
	,, Sept.	Chacornac									
Lutetia ...	52 Nov.	Goldschmidt	9 231	327	81 3	0°16	15 34 2°44	1388			
Calliope ...	52 Nov.	Hind	9 222	59	67 14	0°10	11 53 2°91	1817			
Thalia.....	52 Dec.	Hind	10 258	123	68 10	0°24	13 54 2°63	1554			
Themis ...	53 Apr.	Gasparis	12 279	135	36 1	0°12	10 36 3°14	2037			
Phoebe ...	53 Apr.	Chacornac	9 51	303	214 22	0°25	15 54 2°40	1359			
Proserpine	53 May	Luther	11 357	236	46 4	0°09	13 40 2°66	1581			
Euterpe ...	53 Nov.	Hind	9 175	88	94 2	0°17	16 27 2°35	1311			
Bellona ...	54 Mar.	Luther	10 224	122	145 9	0°15	12 48 2°78	1689			
Amphitrite	{ 54 Mar.	Marth									
	,, Mar.	Pogson	10 255	57	356 6	0°07	14 29 2°55	1491			
	,, Mar.	Chacornac									
Urania ...	54 July	Hind	9 10	31	308 2	0°17	16 0 2°39	1350			
Euphrosyne	54 Sept.	Ferguson	10 54	94	31 26	0°22	10 33 3°16	2048			
Pomona ...	54 Oct.	Goldschmidt	11 55	209	221 6	0°08	14 17 2°58	1512			
Polyhymnia	54 Oct.	Chacornac	10 22	340	9 2	0°35	12 5 2°88	1787			
—	55 Apr.	Chacornac	11 350	188	184 5	0°07	13 41 2°65	1574			
Leucothea	55 Apr.	Luther									

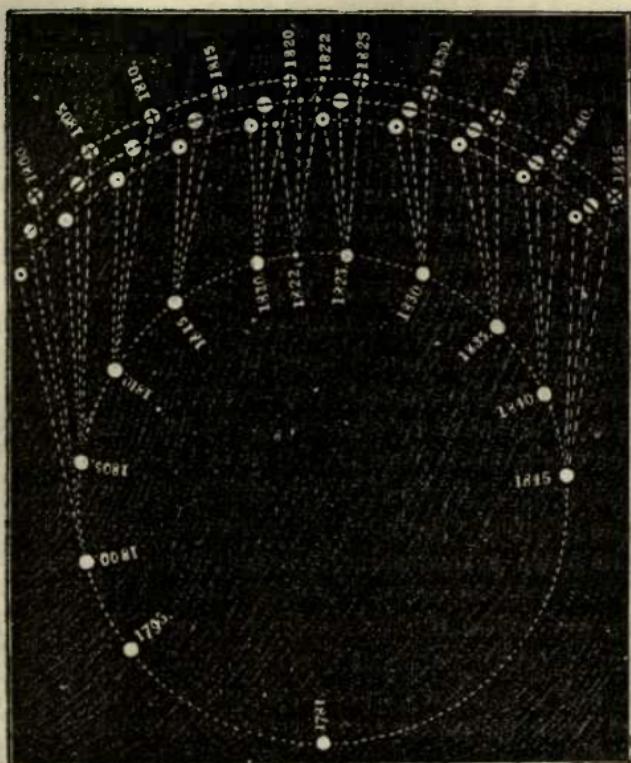


Fig. 4.

LE VERRIER AND ADAMS' PLANET.

- 1.—Surprise excited by the discovery.—2. How a body may be discovered without seeing it.—3. Generalisation of the principle.—4. Its application to the case of Neptune.—5. Condition of the solar system before the discovery.—6. Observed disturbances of Uranus.—7. Great regularity of these effects.—8. How they would be produced by a more distant planet.—9. Calculations of Le Verrier and Adams.—10. Elements of the sought planet according to these geometers.—11. Its actual discovery.—12. Its corrected elements.—13. Discrepancies between the actual and predicted elements explained.—14. Comparison of the effects of the real and predicted planets.—15. The discovery not to be ascribed to chance.—16. The period of Neptune computed.—17. Computation of his distance.—18. Its prodigious orbital motion.—19. Illustrated by a railway train.—20. Its magnitude.—21. Its satellite.—22. Its weight.—23. Its bulk.—24. The sun's light and heat upon it.—25. The sun's apparent diameter seen from it.—26. Its suspected ring.

1. THE universal astonishment which was excited some years ago by the announcement that certain astronomers, whose names

LE VERRIER AND ADAMS' PLANET.

till then were but little known in the scientific world, and not at all to the general public, had discovered the existence of a new planet, without ever having seen it themselves, and without its having been seen by any one else, will not be soon forgotten.

2. Nevertheless, a little reflection will show that there was not so much cause for surprise in such a discovery, as there might at first appear to be; the only cause of the surprise must depend upon the supposition, that the existence of such a body could only be ascertained by the immediate evidence of the eye directed upon it; but surely cases without number will suggest themselves to every one, in which not only the existence of bodies, but their haunts, are ascertained otherwise than by seeing them. The sportsman goes forth, attended by his hounds, in pursuit of the fox; the existence of the game is ascertained by the scent of the hounds, without seeing it, and possibly at a long distance from the place where it lies; by following closely the scent which it has left upon its track, its place of concealment is soon attained, and the game is started.

3. If we generalise the principles suggested by this familiar illustration, we shall find that it amounts to this, that the existence of a body, and the place at which it is to be found, can be ascertained with as much certainty and precision, by closely observing the peculiar effects which that body produces upon other bodies upon which it acts, and by tracing these effects, as if we actually saw the body we are in quest of. It is the peculiar nature of the fox to leave upon the ground on which he treads an odour which characterises him. The organs of the hound are so constituted as to be highly susceptible of being affected by this odour, and a sufficient number of these animals being started over the ground, they are trained to seek for the scented track, and when found to follow it. The game is thus discovered, not by the sense of sight, but by the effects which it has produced upon other bodies, which themselves affect a different sense.

4. Now let us suppose it possible, that a planet moving through the universe, which was never seen by any observer, should produce upon other planets, which are seen and observed, certain effects; that these effects can be seen and ascertained by astronomers, and that the said astronomers can infer from the general principles of their peculiar science, that these effects are such as could only be produced by a planetary body, moving at a given time in a given direction; such effects would, in that case, prove the existence of a planet, even though it were never seen. What the scent is to the hound, these effects are to the not less sagacious instincts of the astronomer.

PERTURBATION EXPLAINED.

Such then were in fact the means by which the discovery of the planet, since called Neptune, was made; a discovery which was incontestably one of the most signal triumphs ever attained by mathematical science, and which marked an era that must be for ever memorable in the history of physical investigation.

If the planets were subject only to the attraction of the sun, they would revolve in exact ellipses, of which the sun would be the common focus; but being also subject to the attraction of each other, which, though incomparably more feeble than that of the presiding central mass, produces sensible and measurable effects, consequent deviations from these elliptic paths, called PERTURBATIONS, take place. The masses and relative motions of the planets being known, these disturbances can be ascertained with such accuracy, that the position of any known planet at any epoch, past or future, can be determined with the most surprising degree of precision.

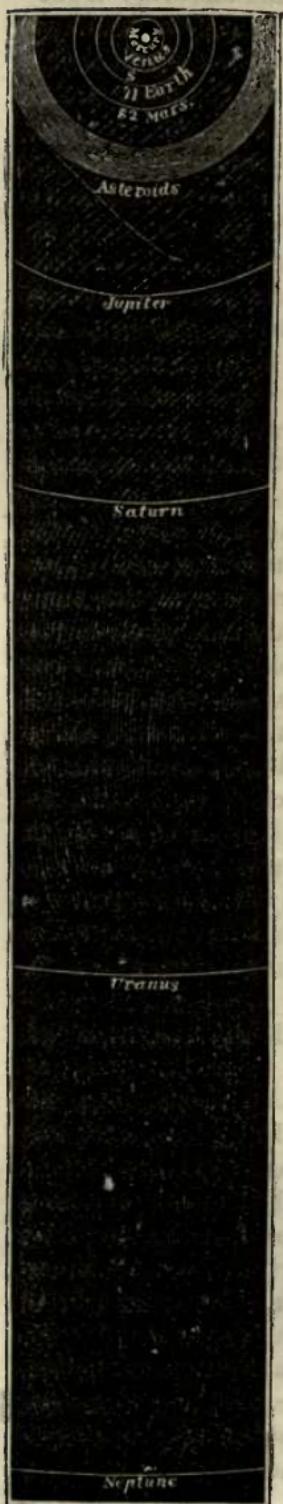
If, therefore, it should be found, that the motion which a planet is observed to have is not in accordance with that which it ought to have, subject to the central attraction of the sun, and the disturbing actions of the surrounding planets, it must be inferred that some other disturbing attraction acts upon it, proceeding from an undiscovered cause, and, in this case, a problem novel in its form and data, and beset with difficulties which might well appear insuperable, is presented to the physical astronomer. If the solution of the problem, to determine the disturbances produced upon the orbit of a planet by another planet, whose mass and motions are known, be regarded as a stupendous achievement in physical and mathematical science, how much more formidable must not the converse question be regarded, in which the disturbances are given to find the planet.

Such was, nevertheless, the problem of which the discovery of Neptune has been the astonishing solution.

Although no exposition of the actual process by which this great intellectual achievement has been effected, could be comprehended without the possession of an amount of mathematical knowledge far exceeding that which is expected from the readers of works much less elementary than the present, we may not be altogether unsuccessful in attempting to illustrate the principle on which an investigation, attended with so surprising a result, has been based, and even the method upon which it has been conducted; so as to strip the proceeding of much of that incomprehensible character, which, in the view of the great mass of those who consider it, without being able to follow the steps of the actual investigation, is generally attached to it, and to show at least

LE VERRIER AND ADAMS' PLANET.

Fig. 1.



the spirit of the reasoning by which the solution of the problem has been accomplished.

For this purpose, it will be necessary, first, to explain the nature and character of those disturbances which were observed and which could not be ascribed to the attraction of any of the known planets; and, secondly, to show in what manner an undiscovered planet, revolving outside the known limits of the solar system, could produce such effects.

5. At the epoch of this celebrated discovery, the solar system was supposed to consist of the principal planets, Mercury, Venus, the Earth, Mars, Jupiter, Saturn, and Uranus, revolving round the sun, in the order in which we have given their names, and at distances bearing to each other the proportion which is represented with tolerable exactness in fig. 1. Between Mars and Jupiter a group of very minute bodies, called planetoids or asteroids, had been discovered, occupying the place of a planet, which had been supposed to be wanting in the system. Since the discovery which now engages us, the number of these planetoids discovered has been greatly increased, its amount being at the time we write (1st February, 1855,) not less than 33.

If the reader will carry in his eye the plan of the solar system thus exhibited, he will find the following observations and reasoning not difficult to comprehend.

6. The planet Uranus, revolving at the extreme limits of the solar system, was the object in which were observed those disturbances which, not being the effects of the action of any of the known planets, raised the question of the possible existence of another planet exterior to it, which might produce them.

After the discovery of that planet by Sir W. Herschel, in 1781, its motions, being regularly observed, supplied the data by

which its elliptic orbit was calculated, and the disturbances produced upon it by the masses of Jupiter and Saturn ascertained, the other planets of the system, by reason of their remoteness, and the comparative minuteness of their masses, not producing any sensible effects. Tables founded on these results were computed, and ephemerides constructed, in which the places at which the planet ought to be found from day to day for the future were duly registered.

The same kind of calculations which enabled the astronomer thus to predict the future places of the planet, would, as is evident, equally enable him to ascertain the places which had been occupied by the planet in times past. By thus examining, retrospectively, the apparent course of the planet over the firmament, and comparing its computed places at particular epochs with those of stars which had been observed, and which had subsequently disappeared, it was ascertained that several of these stars had in fact been Uranus itself, whose planetary character had not been recognised from its appearance, owing to the imperfection of the telescopes then in use; nor from its apparent motion, owing to the observations not having been sufficiently continuous and multiplied.

In this way it was ascertained, that Uranus had been observed, and its position recorded as a fixed star, six times by Flamstead: viz., once in 1690, once in 1712, and four times in 1715;—once by Bradley in 1753, once by Mayer in 1756, and twelve times by Lemonnier between 1750 and 1771.

Now, although the observed positions of these objects, combined with their subsequent disappearance, left no doubt whatever of their identity with the planet, their observed places deviated sensibly from the places which the planet ought to have had, according to the computations founded upon its motions after its discovery in 1781. If these deviations could have been shown to be irregular and governed by no law, they would be ascribed to errors of observation. If, on the other hand, they were found to follow a regular course of increase and decrease in determinate directions, they would be ascribed to the agency of some undiscovered disturbing cause, whose action at the epochs of the ancient observations was different from its action at more recent periods.

The ancient observations were, however, too limited in number and too discontinuous to demonstrate in a satisfactory manner the irregularity or the regularity of the deviation. Nevertheless, the circumstance raised much doubt and misgiving in the mind of Bouvard, by whom the tables of Uranus, based upon the modern observations, were constructed; and he stated that he

LE VERRIER AND ADAMS' PLANET.

would leave to futurity the decision of the question, whether these deviations were due to errors of observation, or to *an undiscovered disturbing agent*. We shall presently be enabled to appreciate the sagacity of this reserve.

7. The motions of the planet continued to be assiduously observed, and were found to be in accordance with the tables for about fourteen years from the date of the discovery of the planet. About the year 1795, a slight discordance between the tabular and observed places began to be manifested, the latter being a little in advance of the former, so that the observed longitude L of the planet was greater than the tabular longitude L' . After this, from year to year, the advance of the observed upon the tabular place increased, so that the excess $L - L'$ of the observed above the tabular longitude was continually augmented. This increase of $L - L'$ continued until 1822, when it became stationary, and afterwards began to decrease. This decrease continued until about 1830-31, when the deviation $L - L'$ disappeared, and the tabular and observed longitudes again agreed. This accordance, however, did not long prevail. The planet soon began to fall behind its tabular place, so that its observed longitude L , which before 1831 was greater than the tabular longitude L' , was now less; and the distance $L' - L$ of the observed behind the tabular place increased from year to year, and still increases.

It appears, therefore, that in the deviations of the planet from its computed place, there was nothing irregular and nothing compatible with the supposition of any cause depending on the accidental errors of observation. The deviation, on the contrary, increased gradually in a certain direction to a certain point; and having attained a maximum, then began to decrease, which decrease still continues.

The phenomena must, therefore, be ascribed to the regular agency of some undiscovered disturbing cause.

8. It is not difficult to demonstrate that deviations from its computed place, such as those described above, would be produced by a planet revolving in an orbit having the same or nearly the same plane as that of Uranus, which would be in heliocentric conjunction with that planet at the epoch at which its advance beyond its computed place attained its maximum.

Let $A B C D E F$, fig. 2, represent the arc of the orbit of Uranus described by the planet during the manifestation of the perturbations. Let $N N'$ represent the orbit of the supposed undiscovered planet in the same plane with the orbit of Uranus. Let a, b, c, d, e , and f be the positions of the latter when Uranus is at the points A, B, C, D, E , and F . It is therefore supposed, that Uranus

PERTURBATION OF URANUS.

when at d is in heliocentric conjunction with the supposed planet, the latter being then at d .

The directions of the orbital motions of the two planets are indicated by the arrows beside their paths; and the directions of

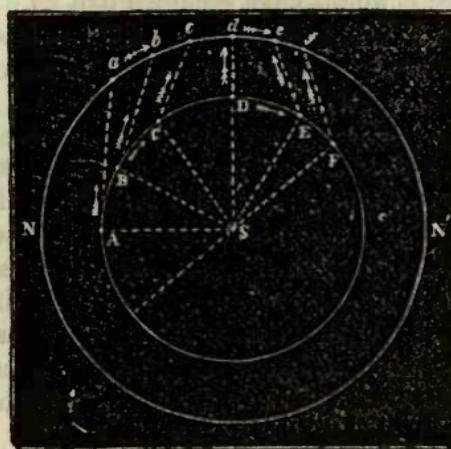


Fig. 2.

the disturbing forces * exercised by the supposed planet on Uranus are indicated by the arrows beside the lines joining that planet with Uranus.

Now, it will be quite evident, that the attraction exerted by the supposed planet at a on Uranus at A tends to accelerate the latter. In like manner, the forces exerted by the supposed planet at b and c upon Uranus at B and c tend to accelerate it. But as Uranus approaches to d , the direction of the disturbing force, being less and less inclined to that of the orbital motion, has a less and less accelerating influence, and on arriving at d , the disturbing force being in the direction $d\bar{d}$ at right angles to the orbital motion, all accelerating influence ceases.

After passing d the disturbing force is inclined *against* the motion, and instead of accelerating retards it; and as Uranus takes successively the positions E , F , &c., it is more and more inclined, and its retarding influence more and more increased, as will be evident if the directions of the retarding force and the orbital motion, as indicated by the arrows, be observed.

* To simplify the explanation, the effect of the attraction of Uranus on the sun is omitted in this illustration. In the chapter on Perturbations in my "Handbook on Astronomy," the method of determining the exact direction of the disturbing force is explained.

It is then apparent, that from A to D the disturbing force, accelerating the orbital motion, will transfer Uranus to a position in advance of that which it would otherwise have occupied; and after passing D, the disturbing force retarding the planet's motion will continually reduce this advance, until it bring back the planet to the place it would have occupied had no disturbing force acted; after which, the retardation being still continued, the planet will fall behind the place it would have had if no disturbing force had acted upon it.

Now it is evident that these are precisely the *kind* of disturbing forces which act upon Uranus; and it may, therefore, be inferred that the deviations of that planet from its computed place are the physical indications of the presence of a planet exterior to it, moving in an orbit whose plane either coincides with that of its own orbit, or is inclined to it at a very small angle, and whose mass and distance are such as to give to its attraction the degree of intensity necessary to produce the alternate acceleration and retardation which have been observed.

Since, however, the intensity of the disturbing force depends conjointly on the quantity of the disturbing mass and its distance, it is easy to perceive that the same disturbance may arise from different masses, provided that their distances are so varied as to compensate for their different weights or quantities of matter. A double mass at a fourfold distance will exert precisely the same attraction. The question, therefore, under this point of view, belongs to the class of indeterminate problems, and admits of an infinite number of solutions. In other words, an unlimited variety of different planets may be assigned, exterior to the system which would cause disturbances observed in the motion of Uranus, so nearly similar to those observed, as to be distinguishable from them only by observations more extended and elaborate than any to which that planet could possibly have been submitted since its discovery.

9. The idea of taking these departures of the observed from the computed place of Uranus, as the data for the solution of the problem to ascertain the position and motion of the planet which could cause such deviations, occurred, nearly at the same time, to two astronomers, neither of whom at that time had attained either the age or the scientific standing which would have raised the expectations of achieving the most astonishing discovery of modern times.

M. Le Verrier, in Paris, and Mr. J. C. Adams, Fellow and Assistant Tutor of St. John's College, Cambridge, engaged in the investigation, each without the knowledge of what the other was

doing, and believing that he stood alone in his adventurous and, as would then have appeared, hopeless attempt. Nevertheless, both not only solved the problem, but did so with a completeness that filled the world with astonishment and admiration, in which none more ardently shared than those who, from their own attainments, were best qualified to appreciate the difficulties of the question.

The question, as has been observed, belonged to the class of indeterminate problems. An infinite number of different planets might be assigned which would be equally capable of producing the observed disturbances. The solution, therefore, might be theoretically correct, but practically unsuccessful. To strip the question as far as possible of this character, certain conditions were assumed, the existence of which might be regarded as in the highest degree probable. Thus it was assumed that the disturbing planet's orbit was in or nearly in the plane of that of Uranus, and therefore in that of the ecliptic; that its motion in this orbit was in the same direction as that of all the other planets of the system, that is, according to the order of the signs; that the orbit was an ellipse of very small eccentricity; and, in fine, that its mean distance from the sun was, in accordance with the general progression of distances noticed by Bode, nearly double the mean distance of Uranus. This last condition, combined with the harmonic law, gave the inquirer the advantage of the knowledge of the period, and therefore of the mean heliocentric motion.

Assuming all these conditions as provisional data, the problem was reduced to the determination, at least as a first approximation, of the mass of the planet and its place in its orbit at a given epoch, such as would be capable of producing the observed alternate acceleration and retardation of Uranus.

The determination of the heliocentric* place of the planet at a given epoch would have been materially facilitated if the exact time at which the amount of the advance ($L-L'$) of the observed upon the tabular place of the planet had attained its maximum were known; but this, unfortunately, did not admit of being ascertained with the necessary precision. When a varying quantity attains its maximum state, and, after increasing, begins to diminish, it is stationary for a short interval; and it is always a matter of difficulty, and often of much uncertainty, to determine the exact moment at which the increase ceases and the decrease commences. Although, therefore, the heliocentric place of the

* That is, the place in which the planet would appear to be, if the observer were at the centre of the system, where the sun is.

LE VERRIER AND ADAMS' PLANET.

disturbing planet could be nearly assigned about 1822, it could not be determined with the desired precision.

Assuming, however, as nearly as was practicable, the longitude of Uranus at the moment of heliocentric conjunction * with the disturbing planet, this, combined with the mean motion of the sought planet, inferred from its period, would give a rough approximation to its place for any given time.

10. Rough approximations were not, however, what MM. Le Verrier and Adams sought. They aimed at more exact results; and, after investigations involving all the resources and exhausting all the vast powers of analysis, these eminent geometers arrived at the following elements of the undiscovered planet:—

	Le Verrier.	Adams.
Epoch of the elements	1 Jan. 1847.	1 Jan. 1846.
Mean longitude at the epoch . . .	$318^{\circ} 47' 4''$	$323^{\circ} 2'$
Mean distance of planet from sun . .	$36 \cdot 1539$	$37 \cdot 2474$
Eccentricity of the orbit	$0 \cdot 107610$	$0 \cdot 120615$
Longitude of perihelion	$284^{\circ} 45' 8''$	$299^{\circ} 11'$
Mass (sun = 1)	$0 \cdot 00010727$	$0 \cdot 00015003$

11. On the 23rd September, 1846, Dr. Galle, one of the astronomers of the Royal Observatory at Berlin, received a letter from M. Le Verrier, announcing to him the principal results of his calculations, informing him that the longitude of the sought planet must then be 326° , and requesting him to look for it. Dr. Galle, assisted by Professor Encké, accordingly did "look for it," and found it that very night. It appeared as a star of the 8th magnitude, having the longitude of $326^{\circ} 52'$, and consequently only $52'$ from the place assigned by M. Le Verrier. The calculations of Mr. Adams, reduced to the same date, gave for its place $329^{\circ} 19'$, being $2^{\circ} 27'$ from the place where it was actually found.

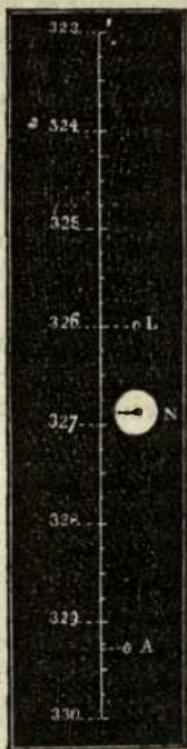
To illustrate the relative proximity of these remarkable predictions to the actual observed place, let the arc of the ecliptic, from long. 323° to long. 330° , be represented in fig. 3. The place assigned by M. Le Verrier for the sought planet is indi-

* Two objects are said to be in heliocentric conjunction, when they are so placed that they would be seen in the same direction by an observer looking at them from the sun.

NEPTUNE DISCOVERED.

cated by the small circle at L, that assigned by Mr. Adams by the small circle at A, and the place at which it was actually found by the dot at N. The distances of L and A from N may be appreciated by the circle which is described around the dot N, and which represents the apparent disk of the moon.

Fig. 3.



The distance of the observed place of the planet from the place predicted by M. Le Verrier was less than two diameters, and from that predicted by Mr. Adams less than five diameters of the lunar disc.

12. In obtaining the elements given above, Mr. Adams based his calculations on the observations of Uranus made up to 1840, while the calculations of M. Le Verrier were founded on observations continued to 1845. On subsequently taking into computation the five years ending 1845, Mr. Adams concluded that the mean distance of the sought planet would be more exactly taken at 33.33.

After the planet had been actually discovered, and observations of sufficient continuance were made upon it, the following proved to be its more exact elements:—

	Greenwich.
Epoch of the elements	1 Jan. 1847, M. Noon.
Mean longitude at the epoch	$328^{\circ} 32' 44''\cdot2$.
Mean distance from sun	30.0367.
Eccentricity of orbit	0.00871946.
Longitude of perihelion	$47^{\circ} 12' 6''\cdot50$.
Longitude of ascending node	$130^{\circ} 4' 20''\cdot81$.
Inclination of orbit	$1^{\circ} 46' 58''\cdot97$.
Periodic time	164.6181 years.
Mean annual motion	$2^{\circ}\cdot18688$.

13. Now it will not fail to strike every one who devotes the least attention to this interesting question, that considerable discrepancies exist, not only between the elements presented in the two proposed solutions of this problem, but between the actual elements of the discovered planet and both of these solutions.

LE VERRIER AND ADAMS' PLANET.

There were not wanting some who, viewing these discordances, did not hesitate to declare that the discovery of the planet was the result of chance, and not, as was claimed, of mathematical reasoning, since, in fact, the planet discovered was not identical with either of the two planets predicted.

To draw such a conclusion from such premises, however, betrays a total misapprehension of the nature and conditions of the problem. If the problem had been determinate, and, consequently, one which admits of but one solution, then it must have been inferred, either that some error had been committed in the calculations which caused the discordance between the observed and computed elements, or that the discovered planet was not that which was sought, and which was the physical cause of the observed disturbances of Uranus. But the problem, as has been already explained, being more or less indeterminate, admits of more than one,—nay, of an indefinite number of different solutions, so that many different planets might be assigned which would equally produce the disturbances which had been observed; and this being so, the discordance between the two sets of predicted elements, and between both of them and the actual elements, are nothing more than might have been anticipated, and which, except by a chance, against which the probabilities were millions to one, were, in fact, inevitable.

So far as depended on reasoning, the prediction was verified; so far as depended on chance it failed. Two planets were assigned, both of which lay within the limits which fulfilled the conditions of the problem. Both, however, differed from the true planet in particulars which did not affect the conditions of the problem. All three were circumscribed within those limits, and subject to such conditions as would make them produce those deviations or disturbances which were observed in the motions of Uranus, and which formed the immediate subject of the problem.

14. It may be satisfactory to render this still more clear, by exhibiting in immediate juxtaposition the motions of the hypothetical planets of MM. Le Verrier and Adams and the planet actually discovered, so as to make it apparent that any one of the three, under the supposed conditions, would produce the observed disturbances. We have accordingly attempted this in fig. 4, where the orbits of Uranus, of Neptune, and of the planets assigned by MM. Le Verrier and Adams are laid down, with the positions of the planets respectively in them for every fifth year, from 1800 to 1845 inclusively. This plan is, of course, only roughly made; but it is sufficiently exact for the purposes of the present illustration. The places of Uranus are marked by O,

DISCREPANCIES EXPLAINED.

those of Neptune by \odot , those of M. Le Verrier's planet by \ominus , and those of Mr. Adams' planet by \oplus .

It will be observed that the distances of the two planets assigned by MM. Le Verrier and Adams, as laid down in the diagram, differ less from the distance of the planet Neptune than the mean distances given in their elements differ from the mean distance of Neptune. This is explained by the eccentricities of the orbit, which, in the elements of both astronomers, are considerable, being nearly an eighth in one and a ninth in the other, and by the positions of the supposed planets in their respective orbits.

If the masses of the three planets were equal, it is clear that the attraction with which Le Verrier's planet would act upon Uranus, would be less than that of the true planet, and that of Adams' planet still more so, each being less in the same ratio as the square of its distance from Uranus is greater than that of Neptune. But if the planets are so adjusted that what is lost by distance is gained by the greater masses, this will be equalised, and the supposed planet will exert the same disturbing force as the actual planet, so far as relates to the effects of variation of distance. It is true that, throughout the arcs of the orbits over which the observations extend, the distances of the three planets in simultaneous positions are not everywhere in exactly the same ratio, while their masses must necessarily be so; and, therefore, the relative masses, which would produce perfect compensation in one position, would not do so in others. This cause of discrepancy would operate, however, under the actual conditions of the problem, in a degree altogether inconsiderable, if not insensible.

But another cause of difference in the disturbing action of the real and supposed planets would arise from the fact, that the directions of the disturbing forces of all the three planets are different, as will be apparent on inspecting the figure in which the degree of divergence of these forces at each position of the planets is indicated; but it will be also apparent, that this divergence is so very inconsiderable that its effect must be quite insensible in all positions in which Uranus can be seriously affected. Thus, from 1800 to 1815, the divergence is very small. It increases from 1815 to 1835; but it is precisely here, near the epoch of heliocentric conjunction, which took place in 1822, that all the three planets cease to have any direct effect in accelerating the motion of Uranus. When the latter planet passes this point sufficiently to be sensibly retarded by the disturbing action, as is the case after 1835, the divergence again becomes inconsiderable.

From these considerations it will therefore be understood, that

the disturbances of the motion of Uranus, so far as these were ascertained by observation, would be produced without sensible difference, either by the actual planet which has been discovered, or by either of the planets assigned by MM. Le Verrier and Adams, or even by an indefinite number of others which might be assigned, either within the path of Neptune, or between it and that of Adams' planet, or, in fine, beyond the latter—within certain assignable limits.

15. That the planets assigned by MM. Le Verrier and Adams are not identical with the planet to the discovery of which their researches have conducted practical observers is, therefore, true; but it is also true that, if they or either of them had been identical with it, such excessive amount of agreement would have been purely accidental, and not at all the result of the sagacity of the mathematician. All that human sagacity could do with the data presented by observation was done. Among an indefinite number of *possible* planets capable of producing the disturbing action, two were assigned, both of which were, for all the purposes of the inquiry, so nearly coincident with the real planet as inevitably and immediately to lead to its discovery.

16. It might appear from considering merely the enormous distance of this planet from the earth, that the problem to ascertain the rate of its motion, and the time it takes to make a complete revolution round the sun, would be attended with great difficulty; nothing, on the contrary, can be more easy or simple. By observing the place of the planet with precision on any given night,—say, for example, on the 1st January, 1853,—and again on the 1st January, 1854, it will be found to have moved through $2\cdot187^\circ$; we infer, therefore, that this is the rate of its annual motion; and this inference would be verified by repeating the same observation on the 1st of January, 1855, and, in a word, on the same night in each succeeding year.

Having thus ascertained that Neptune moves round the sun at the rate of $2\cdot187^\circ$ per annum, the question is: how long he will take to make a complete revolution—that is 360° —round the sun; and this, it is clear, is a question in the simple Rule of Three, that can be solved by any school-boy, and is thus stated—

$$2\cdot187^\circ : 360^\circ :: 1 \text{ year} : \frac{360}{2\cdot187} = 164\cdot6 \text{ years.}$$

Thus it appears that this planet will make a complete revolution round the sun in about 164 years and 7 months, and although not more than a few years have elapsed since the date of its discovery, we are just as certain, that it will complete its revolution in that interval as our posterity will be, who will witness the completion of its period, in the year of our Lord 2011.

DISTANCE OF NEPTUNE.

17. There is a remarkable astronomical law which was discovered, as a matter of fact, by Kepler, and shown by Newton to be a necessary consequence of the principle of universal gravitation, called the harmonic law; according to this celebrated law, the successive distances of the planets from the sun, have a certain fixed relation to their times of revolutions, shortly called their periodic times, by means of which their relative distances can be easily computed, when their periodic times are known. This celebrated law is expressed as follows:—

The squares of the numbers which express the periodic times of any two planets, are in the same proportion as the cubes of the numbers which express their distances from the sun.

This rule reduces the problem to determine the distance of Neptune from the sun to a question in the simple Rule of Three.

The periodic time of the earth being a year, will be expressed by 1, and that of Neptune will be, as already shown, 164·6; now the squares of these numbers are 1 and 27093. To find the cube of Neptune's distance, is therefore a Rule of Three question stated as follow:—

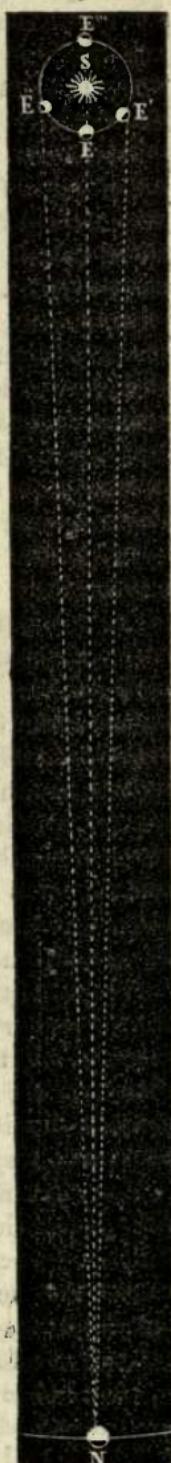
$$1 : 27093 :: 1 : 27093.$$

Therefore this number 27093 is in fact the cube of Neptune's distance from the sun, the earth's distance from the sun being expressed by 1. To find Neptune's distance, therefore, we have only to find the number whose cube is 27093, and by the ordinary processes of arithmetic, that number is found to be 30·034.

We may, therefore, state in round numbers, that Neptune is 30 times farther from the sun than the earth. But the distance of the earth from the sun being, in round numbers, 100 millions of miles; it follows that the distance of Neptune from the sun is, in round numbers, about 3000 millions of miles. Greater numerical precision than this has been attained by the computations of astronomers, but the purpose of our numerous readers will be best served at present by adhering to these round numbers.

18. To convey some notion of the prodigious

Fig. 5.



LE VERRIER AND ADAMS' PLANET.

scale upon which the orbital motion of this planet takes place, we have represented in fig. 5, the orbit of the earth, E, E', E'', E''', the distance of E from s, the sun, being 100 millions of miles ; s n will then be upon the same scale, the distance of Neptune from the sun.

Although it is easy by this expedient to convey a sufficiently exact notion of the relative distances of these planets from the sun, it is by no means so easy to acquire any adequate idea of their actual distances, or what is the same, of the scale of the solar system.

To obtain, even in the case of magnitudes infinitely less than these, any just notions, it is necessary to compare them, and, as it were, to measure them by some standard of magnitude, with which we have a practical familiarity. Let us see then, whether by such an expedient we can obtain some notion, however faint, of the scale of the solar system, at the extreme limit of which Neptune moves.

19. Every one is at this time familiar enough, with the motion of a railway train having a given speed, say, for example, 30 miles an hour ; we know that in such a train, moving with that speed, stoppages included, we can go from London to Liverpool in 7 hours ; in what time, let us ask, could we be transported in such a train from the sun to the earth ? The distance, as already stated, is 100 millions of miles ; if this be divided by 30 we shall find the number of hours which such a journey would take, this number would therefore be 3,333333 hours. If this be divided successively by 24 and by $365\frac{1}{4}$ we shall find the number of days and of years in such a journey ; the result of such a calculation in round numbers will show that such a train will take 380 years to move from the sun to the earth.

But Neptune being, as we have seen, 30 times more distant than the earth from the sun, it would take the same train an interval 30 times longer to move to that planet ; we therefore arrive at the astounding conclusion that a railway-train moving constantly without stoppage would take 114000 years to move from the sun to Neptune, that is to the extreme limit of the solar system.

The circumference of a circle, whose diameter is 6000, is 18849 ; now since the diameter of Neptune's orbit is 6000 millions of miles, its circumference is 18849 millions of miles, and round this circumference the planet moves in 164.6 years, and it therefore moves at the rate of 114,500000 miles per year, or 313500 miles per day, or 13000 miles an hour.

Such is the colossal scale on which the movements of the system are conducted.

20. It will doubtless be asked, whether the magnitude of this

MAGNITUDE OF NEPTUNE.

body have any proportion to such prodigious distances and motions? or whether, indeed, its magnitude at such a distance as 3000 millions of miles, can be at all ascertained? Difficult, nevertheless, as such a problem may seem, it is, on the contrary, among the most easy and simple which are presented to the astronomer.

When a powerful astronomical telescope is directed to a planet, the object which to the naked eye appears as a mere stellar point of light, is seen with a circular disc like that of the moon, but in general much smaller. The visual angle of the moon's disc is 1800"; now it is found that the visual angle of the disc of Neptune is only 2·8", and, therefore, is very nearly 643 times less than the disc of the moon; but the distance of Neptune is 30 times greater than that of the sun, and the distance of the sun is 400 times greater than that of the moon. Therefore the distance of Neptune is 12000 times greater than that of the moon, consequently it will follow, that if the moon were removed to Neptune's distance, its visual angle would be 12000 times less than it is; but from what has been just stated it appears that the visual angle of Neptune is only 643 times less than that of the moon. It follows, therefore, that the actual diameter of Neptune must be greater than the actual diameter of the moon, in the proportion of 12000 to 643, or 19 to 1 very nearly. But since we know the diameter of the moon to be a little more than 2000 miles, it follows that the actual diameter of Neptune will be about 38000 miles.

This is a rough method of calculation which we have adopted to render the point familiar to those who are not accustomed to the more exact methods of astronomical calculations.

How little the result nevertheless varies from the truth, will be perceived when we state, that, according to the most exact observations and calculations of astronomers, the actual diameter of Neptune is 37500 miles.

21. A satellite of this planet was discovered by Mr. Lassell in October, 1846, and was afterwards observed by other astronomers both in Europe and the United States. The first observations then made raised some suspicions as to the presence of another satellite as well as of a ring analogous to that of Saturn. Notwithstanding the numerous observers, and the powerful instruments which have been directed to the planet since the date of these observations, nothing has been detected which has had any tendency to confirm these suspicions.

The existence of the satellite first seen by Mr. Lassell has, however, not only been fully established, but its motion, and the elements of its orbit, have been ascertained, first by the observations of M. O. Struve in September and December, 1847, and later,

LE VERRIER AND ADAMS' PLANET.

and more fully, by those of his late relative M. Auguste Struve, in 1848-9.

From these observations it appears, that the distance of the satellite from the planet at its greatest elongation subtends an angle of $18''$ at the sun ; and since the diameter of the planet subtends an angle of $2''\cdot8$ at the same distance, it follows, therefore, that the distance of the satellite from the centre of the planet is equal to thirteen semidiameters of the latter.

The mean daily angular motion of the satellite round the centre of the planet is, according to the observations of Struve, $61^\circ\cdot2625$, and, consequently, the period of the satellite is—

$$\frac{360}{61\cdot2625} = 5\cdot8763 \text{ days,}$$

or $5^d\ 21^h\ 1\cdot8^m$, a result which is subject to an error not exceeding 5 minutes.

If the semidiameter of the planet be 18750 miles, the actual distance of the satellite is

$$18750 \times 12 = 225000 \text{ miles,}$$

being a little less than the distance of the moon from the earth's centre.

22. If it excite surprise that the dimensions of a globe so enormously distant from the earth as that of Neptune should be so exactly and so easily measured, it will not create less astonishment when we affirm that the mass of matter in that globe can be, and has been weighed, and not only weighed, but weighed with as much or even more precision than that which is attained by the chemist in the operations conducted upon the small masses of matter under his hands.

What then, it will naturally enough be asked, can be the form and structure of the balance, by which an operation so wonderful can be performed ?

Let us see whether we cannot explain this.

If a mass of matter attached to the extremity of a string, the other extremity of which is attached to a fixed point, be whirled round in a circle, of which that fixed point is the centre, the string will be, as every one knows, stretched with a certain force, and that this force will be greater and greater as the velocity with which the body is whirled is increased. Now the moon whirls round the earth with just such a circular motion, and if it were connected by a string with the centre of the earth, that string would be stretched with a force depending upon the velocity of the moon's motion ; but since no such string exists, something else must exist which will exercise the same force upon the moon as the string would, and that something is the earth's attraction.

MOON OF NEPTUNE.

It is proved by theory, and verified by experiment, that the force with which the string connecting such a body with the centre would be stretched, would increase in the same proportion as the square of the velocity of the revolving body increases, other things being the same. If, therefore, the moon's velocity in whirling round the earth were twice what it is, the force with which it would react against the earth's attraction, would be four times greater than it is, and as the earth's attraction would still be the same, the moon, in that case, would escape from her orbit, and would depart to a greater distance from the earth. If, on the other hand, the moon moved with half its present velocity, the force with which it would stretch the string would be four times less than it is, and being then less than the earth's attraction upon it, the moon would fall towards the earth to a much less distance.

But since the moon neither departs to greater distances nor approaches to less distances, it follows that the attraction of the earth upon it is neither more nor less than that with which a string would be stretched which would connect the moon with the centre of the earth.

Now we have seen by what has been explained, that Neptune, as well as the earth, has a moon, and moreover, that this moon whirls round Neptune at a distance a little less than that at which our moon moves round the earth. To simplify the question, let us suppose for a moment that these distances are equal. If then Neptune's moon had the same velocity as ours, a string connecting it with Neptune would be stretched with the same force as that with which a string would be stretched connecting the moon with the earth; and since the attraction of the two planets on their respective moons is represented by the tension of such string, it would follow, in that case, that the two planets would exert equal attractions on moons revolving at equal distances from them. But since these attractions depend only on the quantities of matter in the two planets, or what is the same on their weights, it would, in that case, follow, that the weight of Neptune would be equal to that of the earth.

But Neptune's moon, instead of revolving in the same time as ours, revolves as it appears, by what has been explained, in 5.8763 days. Now we have just explained that the force with which the whirling body would stretch a string increases, other things being the same, in the proportion of the square of its velocity, and since our moon takes 27.322 days to make a complete revolution, while that of Neptune makes a revolution in 5.876 days, the velocity of the latter will be greater than that of the former in the proportion of 5876 to 27322; and consequently the forces with which they will react upon the planetary attractions which

LE VERRIER AND ADAMS' PLANET.

hold them in their orbits will be proportional to the squares of these numbers. But the squares of these numbers, if computed, will be found to be in the proportion of $21\frac{2}{3}$ to 1 very nearly. It would follow, therefore, that the weight of Neptune is $21\frac{2}{3}$ times that of the earth.

But it must not be forgotten that in this calculation we have supposed that the distance of the satellite from Neptune is equal to the distance of the moon from the earth, but in fact the distance of Neptune's satellite is less than that of the moon, in the proportion of 225 to 238, and, therefore, the estimate of the mass of Neptune, computed as above, upon the supposition of the exact equality of the two distances, must be reduced in the same proportion, which would make Neptune's mass 20 times that of the earth.

This, as in the former case, is a very rough method of calculation, adopted to render familiar a problem, which, in its more exact details, would be much too difficult for any but professed astronomers perfectly to understand. By more exact methods it appears that the weight of Neptune is about 19 times that of the earth.

23. The relative bulks, or volumes, of globes being in the proportion of the cubes of their diameters, and the diameter of Neptune being 37500 miles, while that of the earth is about 7900 miles, it follows that the bulk of Neptune is about 107 times greater than that of the earth; or that 107 globes like the earth, being rolled into one, would form a planet equal to Neptune.

24. Since the brightness of the sun's light, and the warmth produced by its heat, decrease in the same proportion as the superficial magnitude of his disc decreases, and since the diameter of that disc decreases in the same proportion as the distance of the observer from the sun increases, it follows that the superficial magnitude of the sun's disc, and therefore the brightness of the light of day, and the warmth of the solar rays, will be less at Neptune than they are at the earth, in the same proportion in which the square of Neptune's distance from the sun is greater than the square of the earth's distance; and since Neptune is 30 times more distant than the earth, it follows that the brightness of day and the sun's warmth at Neptune are 900 times less than at the earth.

25. The apparent diameter of the sun, as seen from Neptune, being 30 times less than from the earth, is,

$$\frac{1800''}{30} = 60''.$$

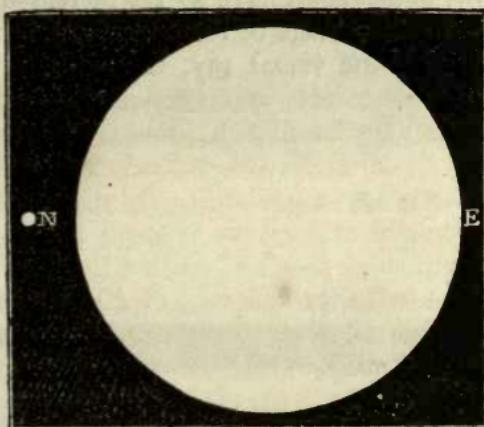
The sun, therefore, appears of the same magnitude as Venus seen as a morning or evening star.

SOLAR LIGHT AND HEAT.

The relative apparent magnitudes are exhibited in fig. 6, at E and N.

It would, however, be a great mistake to infer that the light of the sun at Neptune approaches in any degree to the faintness of that of Venus at the earth. If Venus, when that planet appears as a morning or evening star, with the apparent diameter of 60", had a full disc (instead of one halved or nearly so, like the moon at the quarters), and if the actual intensity of light on its surface were equal to that on the surface of the sun, the light of the

Fig. 6.



planet would be exactly that of the sun at Neptune. But the intensity of the light which falls on Venus is less than the intensity of the light on the sun's surface in the ratio of the square of Venus' distance to that of the sun's semidiameter, upon the supposition that the light is propagated according to the same law as if it issued from the sun's centre; that is, as the square of 37 millions to the square of half a million nearly, or as $37^2 : \frac{1}{4}$, that is, as 5476 to 1. If, therefore, the surface of Venus reflected (which it does not) all the light incident upon it, its apparent light at the earth (considering that little more than half its illuminated surface is seen) is about 11000 times less than the light of the sun at Neptune.

Small, therefore, as is the apparent magnitude of the sun at Neptune, the intensity of its daylight is probably not less than that which would be produced by about 20000 stars shining at once in the firmament, each being equal in splendour to Venus when that planet is brightest.

In addition to these considerations, it must not be forgotten that all such estimates of the comparative efficiency of the illu-

LE VERRIER AND ADAMS' PLANET.

minating and heating power of the sun are based upon the supposition that his light is received under like physical conditions; and that many conceivable modifications in the physical state of the body or medium on or into which the light falls, and in the structure of the visual organs which it affects, may render light of an extremely feeble intensity as efficient as much stronger light is found to be under other conditions.

26. Messrs. Lassell and Challis have at times imagined that indications of some such appendage as a ring, seen nearly edge-wise, were perceptible upon the disc of Neptune. These conjectures have not yet received any confirmation. When the declination of the planet shall have so far increased as to present the ring, if such an appendage be really attached to the planet, at a less oblique angle to the visual ray, the question will probably be decided.

Fig. 1.

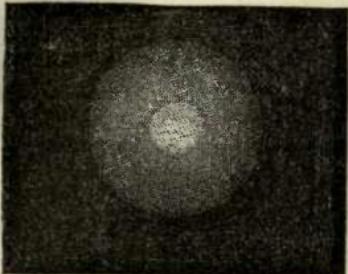


Fig. 2.

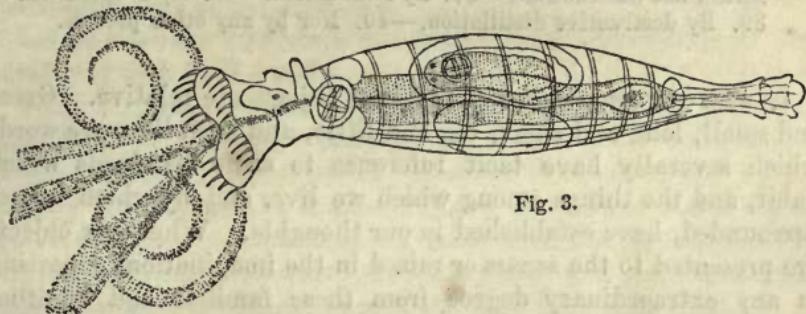


Fig. 3.

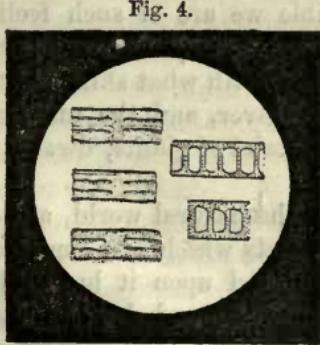


Fig. 4.



Figs. 1, 2.—TELESCOPIC VIEW OF STELLAR CLUSTERS, INCLUDING MANY MILLIONS OF SUNS REDUCED BY DISTANCE TO NEBULOUS SPOTS.

3.—MAGNIFIED VIEW OF THE ROTIFER ANIMALCULE.

Figs. 4, 5.—MAGNIFIED VIEW OF FOSSIL ANIMALCULES SO MINUTE THAT 187 MILLIONS OF THEM WOULD NOT WEIGH MORE THAN A GRAIN.

MAGNITUDE AND MINUTENESS.

-
1. Relative magnitude.—2. Manifestations of Divine wisdom.—3. Smallness of great mountains compared with the bulk of the earth.—4. Of the earth compared with Jupiter and Saturn.—5. With the Sun.—6. With other celestial objects.—7. Minute particles of which all

MAGNITUDE AND MINUTENESS.

bodies are composed.—8. Solid, liquid, and gaseous states—how produced.—9. Mechanical subdivision.—10. Pulverised marble.—11. Inequalities of polished surfaces.—12. Particles of gold on touchstone.—13. Filaments of glass.—14. Micrometer wires.—15. Gold leaf.—16. Gilt silver threads for embroidery.—17. Soap bubbles.—18. Insects' wings.—19. Filaments of wool, silk, and fur.—20. Red Particles in the blood.—21. Animalcules.—22. Spider's web.—23. Minute subdivision of a grain of salt.—24. Of sulphate of copper.—25. Of musk.—26. Of strychnine.—27. Of ammoniacal hyposulphite.—28. Of sugar.—29. Is matter infinitely divisible?—30. Crystallisation of salt.—31. Ultimate atoms.—32. Natural crystals.—33. Plane of cleavage.—34. Determinate figure of ultimate atoms.—35. Principles of mechanical science independent of this hypothesis.—36. Matter not destructible.—37. By combustion.—38. By evaporation.—39. By destructive distillation.—40. Nor by any other process.

1. ALL our conceptions of material objects are relative. Great and small, long and short, big and little, and such like, are words which severally have tacit reference to some standards which habit, and the things among which we live, and by which we are surrounded, have established in our thoughts. Whenever objects are presented to the senses or raised in the imagination, departing in any extraordinary degree from these familiar and habitual standards, emotions of surprise, astonishment, wonder, admiration, ridicule, pity, or contempt, according to varying circumstances, are excited. How susceptible we are of such feelings, and how peculiar is the enjoyment produced by their excitement, will be understood when it is recollectcd with what skill Swift has played upon them in his fiction of Gulliver, and the unbounded pleasure derived by young minds from tales of giants, dwarfs, and fairies.

2. The contemplation and study of the natural world, aided by the lights of science, disclose to us objects which soon emancipate the mind from the narrow limits imposed upon it by all those familiar and habitual standards of magnitude, and show us creative power working with equal sublimity, perfection, and wisdom, upon masses compared with which the most enormous objects around us, the most stupendous mountains, nay, the entire globe of our earth itself, dwindle into insignificant atoms; and, on the other hand, upon objects so minute as to be rendered perceptible to the senses only by extraordinary expedients supplied by the resources of science, such as the microscope. In both extremes of creation are found the same character and manifestations of infinite power, wisdom, and skill, compared with which, the greatest attainable by the most exalted human intellect are mere foolishness; benevolence of purpose, of which there appears neither end, limit, nor cessation; and grandeur of design, compared with which all

MAGNITUDE OF SUN AND PLANETS.

speculations of philosophy, and all visions of poetry, are puerile and ridiculous.

3. We make excursions into Wales or the Scottish Highlands to enjoy the sublime spectacles of Snowdon and Ben Nevis, or to the Alps, to contemplate the stupendous masses of Mont Blanc and Mont Rosa, or to the Andes, or the Himalaya, to behold the still more enormous peaks of Chimborazo or Kunchinginga.

Now, the height of the most lofty summit of the highest of these peaks does not attain to six miles. But astronomers have demonstrated that the earth is a globe eight thousand miles in diameter, so that the height of the most lofty mountain is less than the 1300th part of the diameter.

Let us consider how such mountains should be regarded comparatively with such a globe.

Take a common terrestrial globe, for example, 24 inches in diameter. It is evident that, compared with the earth itself, 3 inches on such a globe would represent 1000 miles, and consequently 18 thousandths or the 55th part of an inch would represent six miles. A mountain six miles high would, therefore, be represented upon the surface of such a globe by a particle of dust, whose diameter would not exceed the 55th part of an inch.

If the base of a mountain six miles high measured 1000 square miles, and the form of the mountain were nearly pyramidal, its solid dimensions would amount to 2000 cubic miles. Now it will be found by the most simple calculations of arithmetic and geometry that a globe 8000 miles in diameter must consist of above 250000 millions of cubic miles. It follows, therefore, that the bulk of the earth must be more than 125 million times greater than the bulk of such a mountain.

4. The discoveries of astronomers, however, have taught us, that stupendous as the earth is when compared to such standards of magnitude, it is small when compared with other globes which in company with it revolve round the sun, and which like it, according to probabilities which amount to moral certainty, are also inhabited worlds; and that, compared with the sun itself, to say nothing of still more enormous bodies which have been discovered, it shrinks to a mere point.

Thus the bulk of the planet Saturn is nearly 900 times, and that of Jupiter nearly 1400 times that of the earth. Yet these, comparatively stupendous as they are, appear to be the theatres of the same physical phenomena, and to play the same part in the creation as the earth.*

5. When we turn our view to the sun we encounter another

* See our Tract on "The Planets."

MAGNITUDE AND MINUTENESS.

order of magnitude. Astronomers have shown that that great central mass has a bulk which is nearly 1,400000 times greater than that of the earth,* or, in other words, that enormous as the globe of the earth is, compared with any standard of magnitude which falls under the immediate observation of the senses, it would be necessary to roll 1,400000 such globes into one to make a globe equal to the sun.

6. Nor do we stop even here. Suns occupying positions in the universe so distant, that to our vision, even when aided by the most powerful telescopes, they appear only as luminous points, have been shown to be many times larger than ours. Comets have been observed and measured, the tails of which have a bulk hundreds of times greater than that of the sun. Clusters consisting of countless thousands of suns are brought by the telescope within our observation which exceed the magnitude, not of the sun only, but of a sun which would fill the entire solar system in a proportion to which it is impossible even to approximate.

Two of these clusters of suns which are reduced by distance to nebulous spots are shown in figs. 1 and 2, page 193.

Thus as astronomy has advanced, it has enabled us to ascend in the scale of the sublime from magnitude to magnitude, each successive discovery reducing all former standards to comparative minuteness, until the understanding and the imagination are confounded by the stupendous spectacle which the material world presents, and lost in that immensity which is the theatre of the creative and beneficent power of the Most High.

7. If our astonishment and admiration are excited by the vast scale of the stellar universe, they are not less awakened by the wonders disclosed when a minute analysis of bodies brings under our view the wonderful structure of their component parts, and the extraordinary manifestation of power and purpose in the organisation of things which would elude the senses unaided by the microscope.

The materials of bodies, even the most massive and ponderous, are infinitely minute, but, minute as they are, their particles or molecules are often formed with the most delicately exact geometrical precision. The separation of these particles, and the discovery of their forms and properties, are among the most marvellous results of scientific research.

8. Material substances are always found in one or other of three states, the solid, the liquid, and the gaseous or vaporous.

Stones, woods, and metals are obvious examples of the solid state, water of the liquid, and air and steam of the gaseous or vaporous state.

* See our Tract on "The Sun."

UNLIMITED DIVISIBILITY.

Solids, generally, by means of heat applied in sufficient quantity and under fit conditions, may be made to pass into the liquid state, the process being called fusion or liquefaction, and all liquids may by like means be made to pass into the gaseous or vaporous state, the process being called vaporisation.

In like manner gases and vapours generally may, by the abstraction of heat, be made to pass into the liquid state, the process being called condensation, and liquids in like manner may be made to pass into the solid state, the process being called congelation or solidification.

In producing these changes upon particular substances, there have been practical difficulties which have prevented the success of the operation, but all analogy supports the conclusion that the principle is general.

These changes, produced by the supply and abstraction of heat, have furnished some of the most efficacious means of determining the nature and properties of the minute component parts of bodies.

9. Bodies may, however, without other physical agency than mere mechanical subdivision, be reduced to particles of surprising minuteness.

As this quality of unlimited divisibility involves conditions of the most profound interest, as well in the sciences as in the arts, we shall offer here several examples in illustration of it.

10. The most solid bodies are capable of unlimited comminution, by a variety of mechanical processes, such as cutting, filing, pounding, grinding, &c. If a mass of marble be reduced to a fine powder by the process of grinding, and this powder be then purified by careful washing, its particles, if examined by a powerful microscope, will be found to consist of blocks having rhomboidal forms, and angles as perfect and as accurate as the finest specimens of calcareous spars. These rhomboids, minute as they are, may be again broken and pulverized, and the particles into which they are divided will still be rhomboids of the same form and possessing the same character. The particles of such powder being submitted to the most powerful microscopic instruments, and the process of pulverization being pushed to the utmost practical limit, it is still found that the same forms are reproduced.

11. The polish of which the surfaces of certain bodies, such as steel, the diamond and other precious stones, are susceptible, is an evidence at once of the limited sensibility of our organs, and the unlimited divisibility of matter. This polish is produced, as is well known, by the friction of emery powder or diamond dust, and consequently each individual grain of such powder or dust must leave a little trench or trace upon the surface submitted to such friction. It is evident, therefore, that after this process has been

completed, the surface which presents to the senses such brilliant polish, and apparently infinite smoothness, is in reality covered with protuberances and indentations, the height and depth of which cannot be less than the diameter of the particles of powder by which the polish has been produced.

12. In the detection of matter in a state of extreme comminution, the sense of sight is infinitely more delicate than that of touch. If we rub a piece of gold upon a touchstone, we plainly see the particles of matter which are left upon the surface of the stone. The touch, however, cannot detect them.

13. In the preceding examples the comminution, however great, cannot be easily submitted to actual measurement. Certain processes, however, in the arts enable us to obtain exact numerical estimates of a minute divisibility, which without them might appear incredible. If a thin tube of glass, being held before the flame of a blow-pipe until the glass be softened and acquire a white heat, be drawn end from end, a thread of glass may be obtained so fine that its diameter will not exceed the two-thousandth part of an inch. This filament of glass will have all the fineness and almost all the flexibility of silk, and yet a bore proportional to that which passed through the original tube will still pass through its centre. The presence of this bore may be rendered manifest by passing a fluid through it.

It has been conjectured that if a filament of this degree of fineness could be obtained of a material that would retain sufficient inflexibility, it might be made to penetrate the flesh without producing pain or injury, inasmuch as its magnitude would be so much less than the pores of the integuments.

14. In the application of the telescope to astronomical purposes, the distance between objects which are present at one and the same time within the field of view of the instrument, is measured by fine threads which are extended parallel to each other across the field of view, and which may be moved towards and from each other until they are made to pass through the objects between which we desire to measure the distance. An experiment, then, which determines the distance between these threads measures the distance between the objects.

But these threads, being placed before the eye-glass of the telescope, and therefore necessarily magnified in the same manner as the objects themselves, would, unless such filaments were of an extreme degree of tenuity, appear in the field of view like great broad bands, and would conceal many of the objects which it might be necessary to observe. It was therefore necessary to resort to the use of filaments of extraordinary minuteness for this.

METALLIC THREADS—SOAP BUBBLE.

purpose. The threads of the web of the spider were used with more or less success; but the late Dr. Wollaston invented a beautiful expedient by which metallic threads of any degree of fineness might be obtained.

Let us suppose a piece of platinum wire, the one-hundredth of an inch in diameter, a fineness easily obtainable by the process of wire-drawing, to be extended along the axis of a cylindrical mould, the one-fifth of an inch in diameter, the wire being thus the twentieth part of the diameter of the mould. Let the mould be then filled with silver in a state of fusion. When this is cold we shall have a cylinder of silver, having in its axis a thread of platinum the twentieth part of its diameter.

This compound cylinder is then submitted to the common process of wire-drawing, during which the platinum in its centre is drawn with the silver, the proportion of their diameters being still maintained. When the wire is drawn to the greatest degree of fineness practicable, a piece of it is plunged in nitric acid, by which the surrounding silver is dissolved, and the platinum wire remains uncovered.

By this process Dr. Wollaston obtained platinum wire so fine, that thirty thousand pieces, placed side by side in contact, would not cover more than an inch.

It would take one hundred and fifty pieces of this wire bound together to form a thread as thick as a filament of raw silk.

Although platinum is the heaviest of the known bodies, a mile of this wire would not weigh more than a grain.

Seven ounces of such wire would extend from London to New York.

15. Gold is subdivided into parts of inconceivable minuteness by the gold beater. A pile of leaf gold, an inch high, would contain 280000 leaves. The thickness of each leaf would therefore be the 280000th part of an inch. Yet such leaves, used for gilding, not only produce a perfect coating of gold, but protect the article they cover from the action of external agents that might otherwise tarnish it.

16. In the manufacture of gold embroidery, threads of silver gilt are used. These threads are produced by flattening very finely drawn gilt wire. The gold which coats an inch of such a thread weighs no more than the eight millionth part of an ounce. Yet this inch may be divided into 100 parts, each of which will be visible without a microscope. In this way the eight hundred millionth part of an ounce of gold is rendered visible. But if a microscope magnifying 500 times, be used, a portion of gold, 500 times less, that is the four hundred thousand millionth part of an ounce will become visible !

17. The optical investigations of Newton disclosed some astonishing examples of the minute divisibility of matter.

A soap-bubble, as it floats in the light of the sun reflects to the eye an endless variety of the most gorgeous tints of colour. Newton showed, that to each of these tints corresponds a certain thickness of the substance forming the bubble; in fact, he showed in general, that all transparent substances, when reduced to a certain degree of tenuity, would reflect these colours.

Near the highest point of the bubble, just before it bursts, is always observed a spot which reflects no colour and appears black. Newton showed that the thickness of the bubble at this black point was the 2,500000th part of an inch! Now, as the bubble at this point possesses the properties of water as essentially as does the Atlantic Ocean, it follows, that the ultimate molecules forming water must have less dimensions than this thickness.

18. The same optical experiments were extended to the organic world, and it was shown, that the wings of insects which reflect beautiful tints resembling mother-of-pearl owe that quality to their extreme tenuity.

Some of these are so thin that 50000 placed one upon the other would not form a heap of more than a quarter of an inch in height!

19. The natural filaments of wool, silk, and fur afford striking examples of the minute divisibility of organised matter. The following numbers show how many filaments of each of the annexed substances placed in contact, side by side, would be necessary to cover an inch:—

Coarse wool	500
Fine Merino wool	1250
Silk	2500

The hairs of the finest furs, such as beaver and ermine, hold a place between the filaments of Merino and silk, and the wools in general have a fineness between that of Merino and coarse wool.

All these objects are sensible to the touch.

It will be remembered that they are compound textures, having a particular structure, each containing very different elements, which are prepared by the processes of nutrition and secretion.

20. Microscopic observations have shown that blood is not as it appears to the naked eye an uniformly red liquid, but that it is a clear transparent colourless liquid, in which float countless numbers of thin, flat, red particles of a round or oval shape. The diameter of these red particles in the human blood, is the 3500th part of an inch. In certain species of animals it is much smaller, and

FOSSIL ANIMALCULES.

measures only the 12000th of an inch. It follows from these dimensions that in a drop of human blood which would remain suspended from the point of a fine needle, there must be about 3,000000 of discs, and in a like drop of the blood of the muskdeer, there would be about 120,000000 ; yet these corpuscles are rendered not only distinctly visible to the senses by the aid of the microscope, but their forms and dimensions are rendered apparent.

21. But these globules, small as they are, are exceeded in minuteness by innumerable creatures, whose existence the microscope has disclosed, and whose entire bodies are inferior in magnitude to the globules of blood.

Microscopic research has disclosed the existence of animals, a million of which do not exceed the bulk of a grain of sand, and yet each of these is composed of members as admirably suited to their mode of life as those of the largest species. Their motions display all the phenomena of vitality, sense, and instinct. In the liquids which they inhabit they are observed to move with the most surprising speed and agility; nor are their motions and actions blind and fortuitous, but evidently governed by choice and directed to an end. They use food and drink, by which they are nourished, and must, therefore, be supplied with a digestive apparatus. They exhibit a muscular power far exceeding in strength and flexibility, relatively speaking, the larger species. They are susceptible of the same appetites, and obnoxious to the same passions, as the superior animals, and, though differing in degree, the satisfaction of these desires is attended with the same results as in our own species.

Spallanzani observes that certain animalcules devour others so voraciously that they fatten and become indolent and sluggish by over-feeding. After a meal of this kind, if they be confined in distilled water so as to be deprived of all food, their condition becomes reduced, they regain their spirit and activity, and once more amuse themselves in pursuit of the more minute animals which are supplied to them. These they swallow without depriving them of life, as by the aid of the microscope, the smaller, thus devoured, has been observed moving within the body of the greater.

An animalcule called a *Rotifer* is represented magnified in an enormous proportion in fig. 3, page 193. This creature has the appearance of throwing out before it two toothed wheels, which, being moved with prodigious velocity, produce whirlpools in the fluid in which it moves, into which other still smaller animalcules are drawn. This apparent apparatus of helical wheels, like those which propel the recently constructed steam-vessels, is supposed

to be in reality the effect of certain ciliated organs attached to the head of the animal, to which it imparts a rapid conical motion. It appears, that it has the power of drawing in these appendages, and when it does so, it changes its form from the oblong shape represented in the figure, to that of a roundish globule.

This creature possesses another property still more astonishing: when withdrawn from the liquid element which is his proper habitation, it is reduced to a grain of dust, so minute as to be visible only by the microscope. In this state it can be kept for long intervals of time, apparently deprived of all life. When, however, it is again immersed in water, it recovers all its original force, and resumes its habits. The most eminent observers have affirmed, that they have submitted the same individual rotifer, several times successively, to these alternations of life and temporary death.

The microscopic researches of Ehrenberg have disclosed most surprising examples of the minuteness of which organised matter is susceptible. He has shown that many species of infusoria exist which are so small that millions of them collected into one mass would not exceed the bulk of a grain of sand, and a thousand might swim side by side through the eye of a needle.

The shells of these creatures are found to exist fossilised in the strata of the earth in quantities so great as almost to exceed the limits of credibility.

By microscopic measurement it has been ascertained that in the slate found at Bilin, in Bohemia, which consists almost entirely of these shells, a cubic inch contains 41000,000000; and as a cubic inch weighs 220 grains, it follows that one hundred and eighty six millions of these shells must go to a grain, each of which would consequently weigh the 186,000000th part of a grain.

All these phenomena lead to the conclusion that these creatures must be supplied with an organisation corresponding in beauty with those of the larger species.

In figs. 4 and 5, page 193, are represented some of the fossil animalecules found in the tripoli of Bilin, magnified in a great proportion.

22. A thread of spider's web, four miles long, weighs little more than a grain. Every one is familiar with the fact that the spider spins a thread by which its own weight hangs. It has been ascertained that this thread consists of 6000 filaments!

23. One of the most obvious means of producing a high degree of subdivision is by dissolving in a large measure of water a small portion of the substance to be divided.

SUBDIVISION BY SOLUTION.

If a grain of salt be dissolved in 1000 grains of distilled water, each grain of the water will contain the 1000th part of the grain of salt; and if a grain of this water be mixed with 1000 grains of distilled water, the 1000th part of a grain of salt which it holds in solution will be uniformly diffused through the latter, so that each grain of the latter solution will contain the 1,000000th part of a grain of salt. The presence of the salt in this second solution can be detected by certain chemical tests.

It is evident that this process may be continued to a still greater extent.

24. A grain of sulphate of copper, dissolved in a gallon of water, will impart to the whole mass of the liquid a plainly perceptible tinge of blue; and a grain of carmine will give its peculiar red to the same quantity of water. It follows, therefore, that a minute drop of such water will contain such a proportion of either of these substances as the drop bears to the gallon.

25. The sense of smelling, although it does not inform us of the mechanical qualities of minute masses of matter, determines, nevertheless, their presence: thus, it is known that a grain of musk will impregnate the atmosphere of a room with its odour for a quarter of a century, or more, without suffering any considerable loss in its weight.

Every particle of the atmosphere which produces the sense of the odour must contain a certain quantity of the musk.

26. The sense of taste, like that of smelling, may determine the presence of matter, without manifesting, by direct evidence, anything concerning its mechanical qualities.

A portion of strychnine, so minute as to be scarcely perceptible to the sight, dissolved in a pint of water, will render every drop of the water bitter. Now, it is evident that in this case, the strychnine being uniformly diffused through the water, the minute portion of it above mentioned is subdivided into as many parts as there are drops of water in a pint.

27. In like manner, a single grain of the salt of silver, called ammoniacal hyposulphite, will impart a flavour of sweetness to a gallon of water. Now, a gallon of water will weigh about seventy thousand grains; and as the flavour of the salt is perceptible in each grain of the water, it follows that one grain of this salt is thus divided into seventy thousand equal parts.

28. A small lump of sugar, dissolved in a cup of tea measuring half a pint, will sweeten the whole perceptibly. In this half-pint of tea there are thirty-one thousand drops. Each drop, therefore, must contain the thirty-one thousandth part of the sugar dissolved, and each such drop is perceptibly sweet. But if the point of a needle be inserted in one of these drops, and withdrawn from

MAGNITUDE AND MINUTENESS.

it, a film of moisture will remain upon it, and the drop will not be visibly diminished. Yet this film of moisture will still be sweet, and will, therefore, contain a fraction of the 31000th part of the lump of sugar, too minute to admit of numerical estimation.

29. It may be asked, whether we are then to conclude, from these various facts, that matter is infinitely divisible, and that there are no original constituent atoms of determinate magnitude and figure, at which all subdivision must cease. Such an inference, however, would be unwarranted, even if we had no other means of deciding the question except those of direct observation, as we should thus impose those limits on the operations of nature which she has imposed upon our powers of observing them.

Although we are unable, by direct observation, to perceive the existence of molecules, or material atoms of determinate figure, yet there are many observable phenomena which render their existence in the highest degree probable, if not positively certain.

30. The most remarkable of such phenomena are observed in the crystallization of salts.

When salt is dissolved in distilled water, as in the preceding example, the mixture presents the appearance of a transparent liquid like water itself, the salt altogether disappearing from sight and touch. The presence of the salt in the water, however, can be established by weighing the solution, which will be found to exceed the original weight of the water by the exact amount of the weight of the salt dissolved.

Now, if this solution be heated to a sufficient temperature, the water will gradually evaporate; but this process of evaporation not affecting the salt, the remaining water will still contain the same quantity of salt in solution, and it will consequently become, by degrees, a stronger and stronger saline solution, the water bearing, consequently, a less and less proportion to the salt. The water will at length be diminished, by evaporation, to that point, that a sufficient quantity does not remain to hold in solution the entire quantity of salt contained in it. When this has taken place, each particle of water which is evaporated leaving behind it the salt which it held in solution, and this salt not being capable of being dissolved by the water which remains, it will float in such water in its solid and natural state, undissolved, just as particles of dust, or other matter not soluble in the water, would do. But the saline particles which thus remain floating in the liquid undissolved, will not collect in irregular solid pieces, but will exhibit themselves in regular figures, terminated by plane surfaces, always forming regular angles, these figures being invariably the same for the same species of salt, but different for

CRYSTALLISATION—ULTIMATE MOLECULES.

different species. There are several circumstances attending the formation of these crystals which merit attention.

If one of these be detached from the others, and the gradual progress of its formation be submitted to observation, it will be found to grow large, always preserving its original figure. Now, since its increase must be produced by the continual accession of saline molecules, disengaged by the water evaporated, it follows that these molecules, or atoms, must have such a shape, that, by attaching themselves successively to the crystal, they will maintain the regularity of its bounding planes, and preserve the angles which these planes form with each other unvaried.

In fact, they must be so shaped, that the structure of the crystal they form may be built up by their regular aggregation into the form which it assumes.

If one of these crystals be taken from the liquid during the process of its formation, and be broken, so as to destroy the regularity of its form, and then restored to the liquid, it will be observed soon to recover its regular form, the atoms of salt, successively dismissed by the evaporating water, filling up the irregular cavities produced by the fracture.

31. Two consequences obviously follow from this phenomenon.

First. That the atoms of the salt dismissed by the water evaporated have such a form, as enables them, by combination, to give to the crystals the shape which they exhibit; and,

Secondly. That the atoms which are successively attached to the crystals in the process of formation, attach themselves in a particular position, to explain which it is necessary to suppose that corresponding sides of the crystals have attractions for each other, so that the atoms of salt not only attach themselves to the sides of the crystals, but place themselves there in a particular position. In a word, we must suppose that the walls of the crystal are built with these atoms in the same manner, and with the same regularity, as the walls of a building are formed with bricks.

All these, and many similar details of the process of crystallization, are, therefore, very evident indications of a determined figure in the ultimate atoms of the substances which are crystallized.

32. But besides these substances thus reduced by art to the form of crystals, there are large classes of bodies which naturally exist in this state.

33. There are certain planes called planes of *cleavage*, in the direction of which natural crystals are easily divided. In substances of the same kind, these planes have always the same relative position; but they differ in different substances.

The surfaces of the planes of cleavage are not always observable before the crystals are divided; but when the crystals are

divided, these surfaces exhibit an intense polish which no effort of art can equal.

We must conclude, therefore, that these planes of cleavage are parallel to the sides of the constituent atoms of the crystals, and their directions therefore form so many conditions for the determination of the shape of these atoms.

This shape being once determined, it is not difficult to assign all the various ways in which they may be arranged, so as to produce regular figures; and we accordingly find that regular figures thus indicated by mathematical reasoning correspond with the forms assumed by the crystals of the same substances.

34. It follows, therefore, from these effects, and the reasoning established upon them, that the substances which are susceptible of crystallization consist of ultimate atoms of different figure. Now, all solid bodies whatever are included in this class, for they have severally been found in, or are reducible to a crystallized form. Liquids crystallize in freezing: several of the gases have been already reduced to the liquid and solid forms, and analysis justifies the conclusion that all are capable of being reduced to this form.

Hence it appears reasonable to presume that all bodies whatever are composed of ultimate atoms, having determinate shape and magnitude; that the different qualities with which we find different bodies endued, depend upon the shape and magnitude of these atoms; that these atoms cannot be disturbed or changed so long as the body to which they belong is not decomposed into other elements, as we find the qualities which depend on them unchangeably the same under all the influences to which they have been submitted.

We must conclude also that these atoms are so minute in their magnitudes that they cannot be observed by any means which human art has yet contrived, but nevertheless that such magnitudes still have limits.

35. It is necessary, however, to observe that notwithstanding the strong analogies which support these conclusions as to the ultimate constitution of material substances, the principles of mechanical science are quite independent of them, and do not rest upon any hypothesis concerning such atomic constitution, and therefore the truth of these principles would not be in any wise disturbed even though it should be established that matter is in the most literal sense infinitely divisible, and is not formed of ultimate atoms.

The basis of mechanical science is *observed facts*; and since the reasoning upon these observed facts is demonstrative, the conclusions, when rightly deduced, have the same degree of certainty as the facts from which they are inferred.

COMBUSTION—DESTRUCTIVE DISTILLATION.

36. The extreme division to which bodies are subjected in many natural and artificial processes, and especially when exposed to the application of heat or fire, has naturally suggested to minds not habituated to the rigid process of scientific reasoning, the idea that bodies are destructible. The ancients, instead of the modern practice of inhumation, disposed of the bodies of their dead by burning them, upon the supposition that their component parts were by such operation destroyed.

The more exact reasoning of modern philosophy, however, teaches us that a power to destroy matter would be as inconceivable in a finite agent as a power to create it.

It is certain that the quantity of matter which exists upon and in the earth has never been diminished by the annihilation of a single atom.

Matter is in fact indestructible by any agency short of divine power. It may be asked, then, what becomes of the matter composing a body which, being subjected to the action of fire, gradually and completely disappears. The answer is, that in this, as well as in all other cases of the apparent destruction of matter, nothing takes place except its subdivision and the change of its form and position.

37. When a body is subjected to the action of heat, its elements are decomposed, and its constituent particles separated, many of them combine with other particles of matter, and form new substances possessing other qualities. Thus, when coal or other fuel is burned, the carbon enters into combination with one of the constituents of the atmosphere called oxygen, and forms a gaseous substance called carbonic acid, which rises into and mixes with the atmosphere. Another element, hydrogen, combines with the same constituent of the atmosphere and forms vapor, which also disperses in the atmosphere.*

Sulphur, which is also occasionally present in fuel, combines with the same constituent of the air, forming a gas called sulphureous acid, which also escapes into the atmosphere. Thus the entire matter of the fuel, with the exception of a small portion of incombustible matter which falls into the ash-pit, is dispersed in the air, and no destruction or annihilation takes place.

That no portion of the matter of the fuel is destroyed or annihilated can be established by the incontrovertible experimental proofs of the chemist, for by the expedients of his science all the products of the combustion which have been just mentioned can be preserved and weighed. The oxygen which has entered into combination with each element of the fuel can be

* See our Tract on "Fire."

MAGNITUDE AND MINUTENESS.

reproduced, as well as the constituents of the fuel itself, the latter of which being weighed, as well as the incombustible ash, the weight of the whole is found to be precisely equal to the weight of the fuel which was burned and apparently destroyed.

38. Liquids when subjected to heat are converted into vapor, and this vapor disperses in the atmosphere, so that the liquid seems to be boiled away; but if the vapor be preserved, as it may be in a separate vessel, and exposed to cold, it will return to the liquid form, and its weight and measure will be found to be precisely the same as that of the liquid evaporated.

39. There is a process in chemistry which is called destructive distillation. The term is objectionable, because it implies a destruction where no destruction takes place. If a piece of wood, being previously weighed, be placed in a close retort and submitted to what is called destructive distillation, it will be found that water, a certain acid, and several gases will issue from it, all of which may be preserved, and mere charcoal will remain in the retort at the end of the process. If the water, acid, and gases which thus escape be weighed with the charcoal, the weight of the whole will be found to be precisely equal to that of the wood which was subjected to destructive distillation.

40. Thus various forms of matter may be fused, evaporated, or submitted to combustion; animals and vegetables may die, organised bodies may be dissolved and decomposed, but in all cases their elementary and constituent parts maintain their existence. The remains of our own bodies after death are deposited in the grave, and enter into innumerable combinations with the materials of the soil, with the vegetation which covers it, and the air which circulates above it.

Consequently, these parts enter into an infinite series of other combinations, forming parts of other organised bodies, animal and vegetable, and which, after having discharged their functions, are thrown off again, mixing with the soil, the air, or organised matter, and once more running through the round of physical combinations.

The constituent atoms of matter are thus constantly performing a circle of duties in the economy of nature with infinitely more certainty and regularity than is observed in the most disciplined army or in the best regulated manufactory.

WORKS

PUBLISHED BY

WALTON AND MABERLY,

UPPER GOWER STREET, AND IVY LANE, PATERNOSTER ROW.

THE Chinese Rebel Chief Hung-siu-tsuen; His History, and the Origin of the Present Insurrection. By the Rev. THEODORE HAMBERG, Hong-Kong. Edited by GEORGE PEARSE, Foreign Secretary of the Chinese Evangelisation Society. Foolscap 8vo, 1s. 6d. cloth.

The *Friend of China* contains a Review of this narrative, attributed to the Bishop of Victoria, Hong Kong, in which it is said—"The author's well-known caution, truthfulness, and candour, give to the little volume under review an interest and a reality which we miss while perusing the flighty, groundless theories and statements hazarded in such works as those by MM. YVAN and CALLERY. . . . The author had with him in his own house a prominent agent in the events narrated, and kinsman of the Insurgent Chief."

London Quarterly Review, No. VII., Price 6s., for April. 1. The Albigenses or Cathari.—2. Sir Astley Cooper and Abernethy.—3. The Prisons of the Continent.—4. Joseph Addison. 5. British Costume, Mediæval and Modern.—6. Milman's Latin Christianity.—7. Popular Criticism: George Gilfillan.—8. The War with Russia. Brief Literary Notices.

Far above Rubies. A MEMOIR OF HELEN S. HERSCHELL. By her Daughter. Edited by the Rev. RIDLEY H. HERSCHELL. Foolscap 8vo, 6s. 6d. cloth.

* * * The Volume also contains the "Bystander," a Series of Papers by Mrs. Herschell, on the following subjects:—1. Introductory.—2. Education.—3. The Law of Consideration.—4. The Deserted Village.—5. Sectarianism.—6. High Church Principles.—7. Love.—8. Elmwood.—9. Spiritual Declension.—10. The Fête.—11. Party Spirit.—12. Training Children.—13. Home Education.—14. An Amusing Companion.—15. Christian Benevolence.—16. Special Providence.—17. Moral Influence.—18. Christian Society.—19. Human Responsibility.

A Memoir of the Rev. James Crabb, LATE OF SOUTHAMPTON. THE "GIPSY ADVOCATE." By JOHN RUDALL, of Lincoln's Inn, Barrister-at-Law. One Vol., Crown 8vo. With a Portrait on Steel. 6s. cloth.

"The Author has presented us with a faithful portraiture of Mr. Crabb's life, character, persevering labours, and never-tiring zeal in the service of his Divine Master."—*Hampshire Independent*.

The Jews. A Brief Sketch of their Present State and Future Expectations. By RIDLEY H. HERSCHELL. Ninth Thousand. Foolscap 8vo, 1s. 6d.

The Crystal Palace. An Essay Descriptive and Critical. From the London Quarterly Review. 8vo, 1s.

EMBORESSED BOOKS FOR THE BLIND.

BY MR. FRERE.

OLD TESTAMENT.

- Genesis, 8s.—Exodus, 7s.
- Joshua, 4s. 6d.—Judges, 4s. 6d.
- Samuel I., 6s.—Samuel II., 5s. 6d.
- Job, 5s.—Proverbs, 5s. 6d.
- Psalms, Part I., 6s. 6d.
- Psalms, Part II., 5s. 6d.
- Isaiah, 7s. 6d.
- Daniel, Esther, and Ruth, 5s. 6d.
- Morning Prayers, 2s.
- Shepherd of Salisbury Plain, 2s.
- Olney Hymns, 2s.

Art of Teaching to Read by Elementary Sounds, 1s. 6d.

NEW TESTAMENT (In 8 Vols.).

- Matthew, 6s.
- Mark, 5s. 6d.
- Luke, 7s.
- John, 5s. 6d.
- Acts, 7s.
- Romans to Corinthians, 6s.
- Galatians to Philemon, 5s. 6d.
- Hebrews to Revelations, 7s.
- A Grammar, 1s.
- Five Addresses to those who wish to go to Heaven, 1s. 6d.

JURISPRUDENCE.

ELEMENTS of Jurisprudence. By CHARLES JAMES FOSTER, M.A., LL.D., Professor of Jurisprudence in University College, London. Crown 8vo, 5s. cloth. "Mr. Foster treats his subject in a masterly manner, and his volume may be read with profit both by students and men of the world."—*Athenaeum*.

RHETORIC.

ELEMENTS of Rhetoric; A Manual of the Laws of Taste, including the Theory and Practice of Composition. By SAMUEL NEIL, Author of "The Art of Reasoning." Large 12mo, 4s. 6d. cloth.

LOGIC.

THE Art of Reasoning; A Popular Exposition of the Principles of Logic, Inductive and Deductive, with an Introductory Outline of the History of Logic, and an Appendix on Recent Logical Developments. By SAMUEL NEIL. Crown 8vo, 4s. 6d.

"This work is of undoubted merit. It displays a great thoughtfulness and research, and contains a vast amount of useful information on the subject of which it treats. The author seems to have thoroughly mastered his subject, and to the illustration of it has skilfully applied his extensive and varied knowledge."—*Glasgow Constitutional*.

An Investigation of the Laws of Thought, on which are founded the Mathematical Theories of Logic and Probabilities. By GEORGE BOOLE, Professor of Mathematics in Queen's College, Cork. One Vol. 8vo, 14s. cloth.

Formal Logic; or, the Calculus of Inference necessary and PROBABLE. By AUGUSTUS DE MORGAN, Professor of Mathematics in University College, London. Cheap Issue, 8vo, 6s. 6d.

HISTORY, ANTIQUITIES, &c.

DICTIONARY of Greek and Roman Geography. Edited by WILLIAM SMITH, LL.D., Editor of the Dictionaries of "Greek and Roman Antiquities," and of "Biography and Mythology." With very numerous Illustrations on Wood. Volume I. (1100 pages), 1l. 16s. cloth lettered.

The Work is continued in Quarterly Parts, each 4s., and will be completed in Two Volumes. Part 12 is now ready (April 1, 1855).

Dictionary of Greek and Roman Biography and Mythology. Edited by WILLIAM SMITH, LL.D., Classical Examiner in the University of London. Medium 8vo. Illustrated by numerous Engravings on Wood. Complete in Three Vols., 5l. 15s. 6d.

Dictionary of Greek and Roman Antiquities. By various Writers. Edited by Dr. WILLIAM SMITH. Second Edition. Revised throughout, with very numerous Additions and Alterations. One thick Volume, medium 8vo, with several hundred Engravings on Wood, 2l. 2s.

A New Classical Dictionary of Ancient Biography, Mythology, AND GEOGRAPHY. Edited by Dr. WILLIAM SMITH. New Edition. One Volume, 8vo, 15s. cloth.

This work comprises the same subjects as are contained in the well-known Dictionary of Lemprière, avoiding its errors, supplying its deficiencies, and exhibiting in a concise form the results of the labours of modern scholars. It will thus supply a want that has been long felt by most persons engaged in tuition.

A Smaller Dictionary of Antiquities; Selected and Abridged from the "Dictionary of Greek and Roman Antiquities." By WILLIAM SMITH, LL.D. New and Cheaper Edition. One small Volume, Two Hundred Woodcuts, 7s. 6d. cloth.

A Smaller Classical Dictionary. Abridged from the larger work. By DR. WILLIAM SMITH. Cheaper Edition. Two Hundred Woodcuts, Crown 8vo, 7s. 6d. cloth.

The Odes of Horace, translated into Unrhymed Metres. With Introductions and Notes. By F. W. NEWMAN, Professor of Latin, University College, London. Crown 8vo. 5s. cloth.

Niebuhr's History of Rome, from the Earliest Times to the Fall of the Western Empire. Translated by BISHOP THIRLWALL, ARCHDEACON HARE, DR. WILLIAM SMITH, and DR. SCHMITZ. Fourth and Cheaper Edition. Three Vols. 8vo, 36s.

Niebuhr's Lectures on Roman History. Translated and Edited by LEONHARD SCHMITZ, Ph. D., Rector of the High School of Edinburgh. New and Cheaper Edition, in Three Vols. 8vo, 24s.

Niebuhr's Lectures on Ancient History, comprising the Asiatic Nations, the Egyptians, Greeks, Carthaginians, and Macedonians. Translated by DR. L. SCHMITZ. Three Vols. 8vo, 1l. 11s. 6d.

In reference to Babylonia, Assyria, and Egypt, it is particularly interesting to notice how clearly the historian foresaw and anticipated all the great discoveries which have since been made in those countries. A thousand points in the history of ancient nations, which have hitherto been either overlooked or accepted without inquiry, are here treated with sound criticism and placed in their true light.

Niebuhr's Lectures on Ancient Ethnography and Geography. Comprising Greece and her Colonies, Italy, the Islands of the Mediterranean, Spain, Gaul, Britain, Northern Africa, and Phœnicia. Translated from the German by DR. LEONHARD SCHMITZ, F.R.S.E., Rector of the High School of Edinburgh, with additions and corrections from his own Notes. Two Vols. 8vo, 1l. 1s. cloth.

A History of Rome; from the Earliest Times to the Death of Commodus, A.D. 192. By DR. L. SCHMITZ, Rector of the High School of Edinburgh, Editor of "Niebuhr's Lectures." New Edition. With 100 Illustrations on Wood. One thick Vol. 12mo, 7s. 6d. cloth.

Questions on Schmitz's History of Rome. By JOHN ROBSON, B.A. 12mo, 2s. cloth.

A History of Greece. With Supplementary Chapters on the Literature, Art, and Domestic Manners of the Greeks. By WILLIAM SMITH, LL.D., Editor of the Dictionaries of "Greek and Roman Antiquities," "Biography," &c. Woodcuts and Maps. Post 8vo, 7s. 6d. cloth.

"A good plan capitally executed, is the characteristic of Dr. Smith's introductory History of Greece."—*Spectator*.

The Book of Almanacs. With Index, by which the Almanac belonging to any year preceding A.D. 2000 can be found; with means of finding New and Full Moons from B.C. 2000 to A.D. 2000. By AUGUSTUS DE MORGAN, Professor of Mathematics in University College, London. Demy 8vo, oblong, 5s. cloth.

"This is quite a novelty in chronological literature. It is an *universal almanac*—universal, that is, as respects time, past, present, and future. The main object of it is, as the compiler states, to supply the place of an old almanac, which is never at hand when wanted; of the older almanac, which never was at hand; and of the universal almanac in every shape! A more useful chronological handbook could scarcely be conceived. It will save an immensity of calculation, and is in many other respects invaluable as a chronological guide and instructor."—*Oxford Herald*.

Four Lectures on the Contrasts of Ancient and Modern History. By F. W. NEWMAN, Professor of Latin in University College, London. Folscap 8vo, 3s. cloth.

A Numismatic Manual; or, Guide to the Collection and Study of Greek, Roman, and English Coins. Illustrated by Engravings of many hundred types, by means of which even imperfect and obliterated pieces may be easily deciphered. By J. Y. AKERMAN, F.S.A. 8vo, 21s. cloth.

POETRY.

DISCOVERY. A POEM. By EDWARD ALDAM LEATHAM, M.A. Folscap 8vo, 2s. 6d. cloth.

"His execution is finished and of a good school."—*Spectator*.

"Mr. Leatham's style is vigorous, his lines are musical, and his versification is correct. * * His peroration is truly eloquent."—*Britannia*.

Love in the Moon; A POEM. With Remarks on that Luminary. By PATRICK SCOTT, Author of "Lelio." Folscap 4to, 5s. 6d. cloth gilt.

Poetical Works of John Keats. Royal 8vo, sewed, 2s.

A Collection of Poetry for the Practice of Elocution. Made for the use of the Ladies' College, Bedford Square. By Professor F. W. NEWMAN. Folscap 8vo, 2s. 6d.

The Georgics of Virgil. Translated into Verse by the Rev. W. H. BATHURST, M.A., Rector of Barwick-in-Elmet. Folscap 8vo, 4s. 6d. cloth.

MISCELLANEOUS.

BUSINESS as it is and as it might be. By JOSEPH LYNDALL. Crown 8vo, 1s. sewed, 1s. 6d. cloth.

* * This Work obtained the Prize of Fifty Guineas offered by the Young Men's Christian Association for the best Essay on "The Evils of the Present System of Business, and the Difficulties they Present to the Attainment and Development of Personal Piety, with Suggestions for their Removal."

Christian Philosophy; or, an Attempt to Display the Evidence and Excellence of Revealed Religion by its Internal Testimony. By VICESIMUS KNOX, D.D., late Fellow of St. John's College, Oxford; and Master of Tunbridge School. Folscap 8vo, 2s. 6d. cloth.

Suggestions on Female Education. Two Introductory Lectures on English Literature and Moral Philosophy, delivered in the Ladies' College, Bedford Square, London. By A. J. SCOTT, A.M., Principal of Owen's College, Manchester, late Professor of the English Language and Literature in University College, London. Folscap 8vo, 1s. 6d.

Guesses at Truth. By TWO BROTHERS. Cheaper Edition. 2 vols. Folscap 8vo. 10s., cloth-lettered.

Mr. Frere's Works on Prophecy.

BRIEF INTERPRETATION OF THE APOCALYPSE. 8vo, 3s. 6d. cloth.

GENERAL STRUCTURE OF THE APOCALYPSE, chiefly relating to the Individual Antichrist of the Last Days. 8vo, 2s.

THREE LETTERS ON THE PROPHECIES. 8vo, 2s.

EIGHT LETTERS ON THE PROPHECIES; viz. on the Seventh Vial; the Civil and Ecclesiastical Periods; and on the Type of Jericho. 8vo, 2s. 6d.

GREAT CONTINENTAL REVOLUTION, marking the expiration of the "Times of the Gentiles." 8vo, 2s. 6d.

STEAM NAVIGATION AND RAILWAYS.

THE Steam Engine, Steam Navigation, Roads, and Railways,
EXPLAINED AND ILLUSTRATED. A New and Cheaper Edition, revised
 and completed to the present time. By DIONYSIUS LARDNER, D.C.L., formerly
 Professor of Natural Philosophy and Astronomy in University College, London.
 One Vol. 12mo, Illustrated with Wood Engravings, 8s. 6d. cloth.

NATURAL PHILOSOPHY AND ASTRONOMY.

THE Electric Telegraph Popularised. With 100 Illustrations. By
 DIONYSIUS LARDNER, D.C.L. From the "Museum of Science and Art." 12mo,
 2s. cloth.

"The reader will find the most complete and intelligible description of
 Telegraphic Apparatus in Dr. Lardner's admirable chapters on the subject."—
North British Review.

FAMILIAR Letters on the Physics of the Earth. By H. BUFF,
 Professor of Physics in the University of Giessen. Edited by Dr. A. W.
 HOFMANN, Professor in the Royal College of Chemistry, London. Feap. 8vo, 5s.
 Introduction.—Gravity and its Effects.—Tides.—Heat within the Earth.—
 Warm Springs.—Hot Springs and Jets of Steam.—Jets of Gas and Mud Volca-
 noes.—Volcanoes and Earthquakes.—Temperature of the Outermost Crust of the
 Earth.—Temperature of the Lowest Layer of the Atmosphere.—Lines of equal
 Heat.—Temperature of the Upper Layers of the Atmosphere.—The Snow Limits,
 —Glaciers.—Temperature of the Waters, and their Influence on Climate.—Cur-
 rents of the Sea.—Winds.—Moisture of the Air and Atmospheric Precipitation.
 —Electricity of the Air, Lightning, and Thunder.

An Elementary Treatise on Mechanics, for the Use of Junior University
 Students. By RICHARD POTTER, A.M., Professor of Natural Philosophy in
 University College, London. Third Edition, 8vo, with numerous Diagrams,
 8s. 6d. cloth.

An Elementary Treatise on Optics, PART I. By RICHARD POTTER,
 A.M. Second Edition, 8vo, corrected, with numerous Diagrams, 9s. 6d. cloth.

An Elementary Treatise on Optics, PART II., Containing the Higher
 Propositions. By RICHARD POTTER, A.M. 8vo, with numerous Diagrams, 12s. 6d.

Twelve Planispheres, forming a Guide to the Stars for every Night in the
 Year, with an Introduction. 8vo, 6s. 6d. cloth.

Ecliptical Charts, Hours, 1, 2, 3, 4, 5, 7, 9, 10, 11, 13, 14, 19,
 and 20, taken at the Observatory, Regent's Park, under the direction of GEORGE
 BISHOP, Esq., F.R.S., &c. 2s. 6d. each.

Astronomical Observations, taken at the Observatory, Regent's Park,
 during the Years 1839—1851, under the direction of GEORGE BISHOP, Esq.,
 F.R.S., &c. 4to, 12s. 6d.

Mr. Bishop's Synoptical Table of the Elements of the Minor
 Planets, between Mars and Jupiter, as known at the beginning of 1855, with
 the particulars relating to their discovery, &c. Arranged at the Observatory,
 Regent's Park. On a Card.

DR. LARDNER'S MUSEUM OF SCIENCE AND ART.

A miscellany of

INSTRUCTIVE AND AMUSING TRACTS ON THE PHYSICAL SCIENCES, AND
ON THEIR APPLICATION TO THE USES OF LIFE.

ILLUSTRATED BY ENGRAVINGS ON WOOD.

DOUBLE VOLUMES.

Volumes 1 to 6 may now be had, strongly bound, 2 Volumes in 1 with Indexes, cloth lettered, price 3s. 6d. each double volume.

"Dr. Lardner's Museum," one of the few works of the kind which can be recommended as at once popular and accurate."—Sir David Brewster.

Contents of Vols. I. and II. (double), 3s. 6d. cloth.

VOL. I., price 1s. 6d., in handsome boards.

PART I., price 5d.

1. The Planets; Are they Inhabited Globes?
2. Weather Prognostics.
3. The Planets. Chap. II.
4. Popular Fallacies in Questions of Physical Science.

PART II., price 5d.

5. Latitudes and Longitudes.
6. The Planets. Chap. III.
7. Lunar Influences.
8. Meteoric Stones and Shooting Stars. Chap. I.

PART III., price 6d.

9. Railway Accidents. Chap. I.
10. The Planets. Chap. IV.
11. Meteoric Stones and Shooting Stars. Chap. II.
12. Railway Accidents. Chap. II.
13. Light.

Contents of Vols. III. and IV. (double), 3s. 6d. cloth.

VOL. III., price 1s. 6d., in handsome boards.

PART VII., price 5d.

27. Locomotion and Transport, their Influence and Progress. Chap. I.
28. The Moon.

29. Common Things.—The Earth.
30. Locomotion and Transport, their Influence and Progress. Chap. II.

PART VIII., price 5d.

31. The Electric Telegraph. Chap. I.

VOL. IV., price 1s. 6d., in handsome boards.

PART X., price 5d.

40. Earthquakes and Volcanoes. Chap. I.
41. The Electric Telegraph. Chap. VII.
42. The Electric Telegraph. Chap. VIII.
43. The Electric Telegraph. Chap. IX.

PART XI., price 5d.

44. Barometer, Safety Lamp, and Whitworth's Micrometric Apparatus.

VOL. II., price 1s. 6d., in handsome boards.

PART IV., price 5d.

14. Common Things.—Air.
15. Locomotion in the United States. Chap. I.
16. Cometary Influences. Chap. I.
17. Locomotion in the United States. Chap. II.

PART V., price 5d.

18. Common Things.—Water.
19. The Potter's Art. Chap. I.
20. Locomotion in the United States. Chap. III.
21. The Potter's Art. Chap. II.

PART VI., price 6d.

22. Common Things.—Fire.
23. The Potter's Art. Chap. III.
24. Cometary Influences. Chap. II.
25. The Potter's Art. Chap. IV.
26. The Potter's Art. Chap. V.

PART VII., price 6d.

32. Terrestrial Heat. Chap. I.
33. The Electric Telegraph. Chap. II.
34. The Sun.

PART IX., price 6d.

35. The Electric Telegraph. Chap. III.
36. Terrestrial Heat. Chap. II.
37. The Electric Telegraph. Chap. IV.
38. The Electric Telegraph. Chap. V.
39. The Electric Telegraph. Chap. VI.

PART X., price 6d.

45. The Electric Telegraph. Chap. X.
46. Earthquakes and Volcanoes. Chap. II.
47. The Electric Telegraph. Chap. XI.

PART XII., price 6d.

48. Steam.
49. The Electric Telegraph. Chap. XII.
50. The Electric Telegraph. Chap. XIII.
51. The Electric Telegraph. Chap. XIV.
52. The Electric Telegraph. Chap. XV.

DR. LARDNER'S MUSEUM (Continued) :—

Contents of Vols. V. and VI. (double), 3s. 6d. cloth.

VOL. V., price 1s. 6d., contains—

PART XIII., price 5d.

- 53. The Steam Engine. Chap. I.
- 54. The Eye. Chap. I.
- 55. The Atmosphere.
- 56. Time. Chap. I.

Part XIV., price 5d.

- 57. The Steam Engine. Chap. II.
- 58. Common Things. Time. Chap. II.

59. The Eye. Chap. II.

60. Common Things. Pumps.

Part XV., price 6d.

- 61. The Steam Engine. Chap. III.
- 62. Common Things. Time. Chap. III.
- 63. The Eye. Chap. III.
- 64. Common Things. Time. Chap. IV.
- 65. Common Things. Spectacles—The Kaleidoscope.

VOL. VI., price 1s. 6d., contains—

PART XVI., price 5d.

- 66. Clocks and Watches, Chap. I.
- 67. Microscopic Drawing and Engraving. Chap. I.
- 68. Locomotive. Chap. I.
- 69. Microscopic Drawing and Engraving. Chap. II.

Part XVII., price 5d.

- 70. Clocks and Watches. Chap. II.
- 71. Microscopic Drawing and Engraving. Chap. III.

72. Locomotive. Chap. II.

73. Microscopic Drawing and Engraving. Chap. IV.

PART XVIII., price 6d.

- 74. Clocks and Watches. Chap. III.
- 75. Thermometer.
- 76. New Planets. Leverrier and Adams' Planet.
- 77. Leverrier and Adams' Planet, concluded.
- 78. Magnitude and Minuteness.

* * Continued in Weekly Numbers at 1d.; Monthly Parts at 5d.; Quarterly Volumes at 1s. 6d., and Half Yearly Volumes at 3s. 6d.

First Book of Natural Philosophy; or, an Introduction to the Study of Statics, Dynamics, Hydrostatics, and Optics, with numerous examples. By SAMUEL NEWTH, M.A., Fellow of University College, London. 12mo, 3s. 6d.

Elements of Mechanics and Hydrostatics. By SAMUEL NEWTH, M.A. Second Edition, small 8vo, 7s. 6d. cloth.

Dr. Lardner's Handbook of Astronomy. From the "Handbook of Natural Philosophy." 37 Plates and 200 Woodcuts. Large 12mo, 16s. 6d. cloth.

Handbook of Natural Philosophy and Astronomy. By DIONYSIUS LARDNER, formerly Professor of Natural Philosophy and Astronomy in University College, London. Three Vols., large 12mo, with very numerous Illustrations on Wood.

FIRST COURSE, One Vol., 12s. 6d. cloth, contains:—Mechanics; Hydrostatics; Hydraulics; Pneumatics; Sound; Optics.

SECOND COURSE, One Vol., 8s. 6d., contains:—Heat; Common Electricity; Magnetism; Voltaic Electricity.

THIRD COURSE, One Vol., 16s. 6d., contains:—Astronomy and Meteorology. With 37 Plates and 200 Woodcuts.

* * Any volume may be purchased separately.

MATHEMATICS, &c.

ELEMENTS of Arithmetic. By AUGUSTUS DE MORGAN, Professor of Mathematics in University College, London. Fifth Edition, with Eleven Appendixes, Royal 12mo, 5s. cloth.

De Morgan's Trigonometry and Double Algebra. Royal 12mo, 7s. 6d. cloth.

Barlow's Tables of Squares, Cubes, Square Roots, Cube Roots, AND RECIPROCALS, up to 10,000. Stereotype Edition, examined and corrected. Under the superintendence of the Society for the Diffusion of Useful Knowledge. Royal 12mo, cloth, 8s.

Arithmetical Books and Authors. From the Invention of Printing to the present time; being Brief Notices of a large Number of Works drawn up from actual inspection. By AUGUSTUS DE MORGAN, Professor of Mathematics in University College, London. Cheap issue. Royal 12mo, 2s. 6d. cloth.

"A great number of persons are employed in teaching Arithmetic in the United Kingdom. In publishing this work, I have the hope of placing before many of them more materials for the prevention of inaccurate knowledge of the literature of their science than they have hitherto been able to command, without both expense and research."—*Preface*.

A Course of Arithmetic as Taught in the Pestalozzian School, WORKSOP. By J. L. ELLENBERGER. 12mo, 5s. cloth.

The First Book of Euclid Explained to Beginners. By C. P. MASON, B.A., Fellow of University College, and Principal of Denmark Hill Grammar School. Fcap. 8vo, 1s. 9d. cloth.

Reiner's Lessons on Form; or, an Introduction to Geometry, as given in a Pestalozzian School, Cheam, Surrey. 12mo, with numerous Diagrams, 3s. 6d. cloth.

A First Book on Plane Trigonometry. Geometrical Trigonometry, and its applications to Surveying, with numerous Examples. For the use of Schools. By G. W. HEMMING, M.A., Fellow of St. John's College, Cambridge, and Author of a Treatise on the "Differential and Integral Calculus." With Diagrams, 12mo, cloth limp, 1s. 6d.

Ritchie's Principles of Geometry, familiarly Illustrated, and applied to a variety of useful purposes. Designed for the Instruction of Young Persons. Second Edition, revised and enlarged, 12mo, with 150 Woodcuts, cloth limp, 1s. 6d.

Tables of Logarithms, Common and Trigonometrical, to Five PLACES. Under the Superintendence of the Society for the Diffusion of Useful Knowledge. Fcap. 8vo, cloth limp, 1s. 6d.

Lessons on Number, as given at the Pestalozzian School, Cheam, Surrey. By CHARLES REINER. The Master's Manual. New Edition. 12mo, cloth, 5s. The Scholar's Praxis. 12mo, 2s. bound.

GREEK.

THE Anabasis of Xenophon. Expressly for Schools. With Notes, a Geographical and Biographical Index, and a Map. By J. T. V. HARDY, B.A., Principal of Huddersfield College; and ERNEST ADAMS, Classical Master in University College School. 12mo, 4s. 6d. cloth.

Lexicon to Aeschylus. Containing a Critical Explanation of the more Difficult Passages in the Seven Tragedies. By the Rev. W. LINWOOD, A.M., M.R.A.S. Second Edition. Revised. 8vo, 12s. cloth.

New Greek Delectus; Being Sentences for Translation from Greek into English, and English into Greek; arranged in a Systematic Progression. By DR. RAPHAEL KUHNER. Translated and Edited from the German, by DR. ALEXANDER ALLEN. Third Edition, revised. 12mo, 4s. cloth.

Four Gospels in Greek. For the use of Schools. Fcap. 8vo. cloth limp, 1s. 6d. This part of the Greek Testament is printed separately for the use of Students beginning to learn Greek, the Evangelists being more generally read than the rest of the Testament.

London Greek Grammar. Designed to exhibit, in small compass, the Elements of the Greek Language. Edited by a GRADUATE of the University of Oxford. Fifth Edition. 12mo, cloth limp, 1s. 6d.

Greek Testament. GRIESBACH'S TEXT, with the various readings of MILL and SCHOLZ. Second Edition, revised. Fcap. 8vo, cloth, 6s. 6d.; morocco, 12s. 6d.

Plato. The Apology of SOCRATES, CRITO, and part of the PHAEDO, with English Notes, a Life of Socrates, &c. Edited by DR. W. SMITH. Second Edition. 12mo, cloth, 5s.

Robson's Constructive Greek Exercises. 12mo, cloth, 7s. 6d.

* * This Work, which was originally intended to be a new edition of "Allen's Constructive Greek Exercises," will take the place of that book. The general principles of both are identical.

Introduction to the Art of Composing Greek Iambics, in Imitation of the Greek Tragedians. Designed for the use of Schools. By the Rev. CHARLES TAYLER. 12mo, 2s. 6d.

What is the Power of the Greek Article; and how may it be expressed in the English Version of the New Testament? By JOHN TAYLOR. 8vo, 2s. 6d.

LATIN.

NEW Latin Delectus; being Sentences for Translation from Latin into English, and English into Latin; arranged in a Systematic Progression, on the plan of the Greek Delectus. By DR. ALEXANDER ALLEN. Third Edition, 12mo, 4s. cloth.

New Latin Reading-Book; Short Sentences, Easy Narrations, and Descriptions, from Cæsar's Gallic War, arranged in Systematic Progression. With a Dictionary. Second Edition, revised. 12mo, 2s. 6d. cloth.

Constructive Latin Exercises, for teaching the Elements of the Language on a System of Analysis and Synthesis; with Latin Reading Lessons, and copious Vocabularies. By JOHN ROBSON, B.A., late Assistant Master in University College School. Third Edition, thoroughly revised. 12mo, 4s. 6d. cloth.

London Latin Grammar; including the Eton Syntax and Prosody in English, accompanied with Notes. Edited by a GRADUATE of the University of Oxford. Fifteenth Edition. 12mo, 1s. 6d. cloth limp.

First Latin Reading Lessons; with complete Vocabularies. Intended as an Introduction to Cæsar. By JOHN ROBSON, B.A., Assistant Master in University College School. 12mo, 2s. 6d. cloth.

The Principal Roots of the Latin Language, simplified by a display of their Incorporation into the English Tongue; with copious Notes. By HENRY HALL. Fifth Edition. 12mo, 1s. 6d. cloth limp.

The Germania of Tacitus. With Ethnological Dissertations and Notes. By DR. R. G. LATHAM. Author of the "English Language," &c. With a Map. Demy 8vo, 12s. 6d.

Tacitus, Germania, Agricola, and First Book of the Annals. With English Notes and BOTTIGER'S Remarks on the style of TACITUS. Third Edition revised and much improved. Edited by DR. W. SMITH. 12mo, 5s. cloth.

Caesar for Beginners. Latin and English; with the Original Text at the end. 12mo, 3s. 6d. cloth.

Mythology for Versification; or, a Brief Sketch of the Fables of the Ancients, prepared to be rendered into Latin verse. By the late Rev. F. HODGSON, M.A. (Provost of Eton). New Edition. 12mo, 3s. bound. KEY to Ditto. 8vo, 7s.

Select Portions of Sacred History, conveyed in sense for Latin Verses. By the late Rev. F. HODGSON, M.A. (Provost of Eton). Third Edition. 12mo, 3s. 6d. cloth. KEY to Ditto. Royal 8vo, 10s. 6d. cloth.

Sacred Lyrics; or, Extracts from the Prophetical and other Scriptures of the Old Testament; adapted to Latin Versification in the principal Metres of HORACE. By the late Rev. F. HODGSON, M.A. (Provost of Eton). 12mo, 6s. 6d. cloth. KEY to Ditto. 8vo, 12s. cloth.

Latin Authors. Selected for the use of Schools; containing portions of Phædrus, Ovid's Metamorphoses, Virgil's Æneid, Cæsar and Tacitus. 12mo, 1s. 6d. cloth.

HEBREW.

GRAMMAR of the Hebrew Language. By HYMAN HURWITZ, late Professor of Hebrew in University College, London. Fourth Edition, revised and enlarged. 8vo, 13s. cloth. Or in Two Parts, sold separately:—ELEMENTS, 4s. 6d. cloth; ETYMOLOGY and SYNTAX, 9s. cloth.

Book of Genesis in English Hebrew; accompanied by an Interlinear Translation, substantially the same as the authorised English version; Philosophical Notes, and a Grammatical Introduction. By W. GREENFIELD, M.R.A.S. Fourth Edition. Cheap Issue. 8vo, 4s. 6d. cloth. With the original Text in Hebrew characters at the end. 8vo, 6s. 6d. cloth.

MAPS.

TEACHING Maps:—I. RIVERS AND MOUNTAINS, of England, Wales, and Part of Scotland. 6d. II.—TOWNS of Ditto. 6d.

Projections. Three Maps. MERCATOR. EUROPE. BRITISH ISLES. Stitched in a Cover, 1s. Single Maps, 4d. each.

Projections; with Outline of Country. Three Maps stitched in a Cover, 1s. Single Maps, 4d. each.

ENGLISH.

THE English Language. By Dr. R. G. LATHAM, F.R.S., late Fellow of King's College, Cambridge. Fourth Edition, greatly enlarged. 2 Vols. 8vo.

An English Grammar for the Use of Schools. By Dr. R. G. LATHAM, F.R.S., late Fellow of King's College, Cambridge. Sixth Edition. 12mo, 4s. 6d. cloth.

Elements of English Grammar, for the Use of Ladies' Schools. By Dr. R. G. LATHAM, F.R.S. Fcap. 8vo, 1s. 6d. cloth.

Elements of English Grammar, for Commercial Schools. By Dr. R. G. LATHAM, F.R.S. Fcap. 8vo, 1s. 6d. cloth.

A Handbook of the English Language. By Dr. R. G. LATHAM, F.R.S.

Second Edition, revised and much improved. Crown 8vo, 7s. 6d. cloth.

The object of the "Handbook" is to present to students for examination, in a more condensed form, the chief facts and reasonings of "The English Language." Less elaborate than that work, it is less elementary than the "English Grammar." Like all the other works by the same author, it gives great prominence to the ethnological relations of our tongue; and insists upon historical investigation, and the application of the general principles of comparative philology, as the true means of exhibiting its real growth and structure, in opposition to the more usual method of treating it as a mass of irregularities. It has the further object of supplying a knowledge of those laws of speech and principles of grammar which apply to language generally.

History and Etymology of English Grammar, for the Use of CLASSICAL SCHOOLS. By Dr. R. G. LATHAM, F.R.S. Fcap. 8vo, 1s. 6d. cloth.**First Outlines of Logic,** applied to Grammar and Etymology. By Dr. R. G. LATHAM. 12mo, 1s. 6d. cloth.**New English Spelling Book.** By the Rev. GORHAM D. ABBOTT. Second Edition, with Reading Lessons. 12mo, sewed, 6d.**First English Reader.** By the Rev. G. D. ABBOTT. 12mo, with Illustrations. 1s. cloth limp.**Second English Reader.** By the Rev. G. D. ABBOTT. 12mo, 1s. 6d. cloth limp.**FRENCH.****MERLET'S French Grammar.** By P. F. MERLET, Professor of French in University College, London. New Edition. 12mo, 5s. 6d. bound. Or, sold in two Parts: PRONUNCIATION and ACCIDENCE, 3s. 6d.; SYNTAX, 3s. 6d. (KEY, New Edition, 3s. 6d.)**Merlet's Traducteur;** Or, HISTORICAL, DRAMATIC, and MISCELLANEOUS SELECTIONS from the best FRENCH WRITERS; accompanied by Explanatory Notes; a selection of Idioms, &c. New Edition. 12mo, 5s. 6d. bound.**Merlet's Dictionary of the Difficulties of the French Language;** containing Explanations of every Grammatical Difficulty; Synonymes explained in a concise manner; Versification; Etymological Vocabulary; Free Exercises, with Notes; Mercantile Expressions, Phrases, and Letters; Elements of French Composition. A new and enlarged Edition. 12mo, 6s. 6d. bound.**Merlet's French Synonymes;** explained in Alphabetical Order, with Copious Examples. (From the "DICTIONARY OF DIFFICULTIES.") 12mo, 2s. 6d. cloth.**Stories from French Writers.** Interlinear (from Merlet's "Traducteur"). 12mo, 2s.**GERMAN.****The Adventures of Ulysses:** a German Reading Book; with a short Grammar and a Vocabulary. By PAUL HIRSCH. Twenty-four Woodcuts. 12mo, 6s. cloth.

Separately,

A Short Grammar of the German Language. 12mo, cloth, 2s.**ITALIAN.****First Italian Course;** Being a Practical and Easy Method of Learning the Elements of the Italian Language. By W. BROWNING SMITH, M.A., Second Classical Master of the City of London School. Royal 18mo, cloth, 3s. 6d.**Panizzi's Italian Grammar.** 12mo, cloth limp, 1s. 6d.

INTERLINEAR TRANSLATIONS.

Cheap Issue, at 1s. 6d. per volume.

LOCKE'S System of Classical Instruction, restoring the Method of Teaching formerly practised in all Public Schools. The Series consists of the following Interlinear Translations with the Original Text, in which the quantity of the doubtful Vowels is denoted; critical and explanatory Notes, &c.

** By means of these Works, that excellent system of Tuition is effectually restored which was established by Dean Colet, Erasmus, and Lily, at the foundation of St. Paul's School, and was then enjoined by authority of the State, to be adopted in all other Public Seminaries of learning throughout the kingdom. Each Volume, 1s. 6d.

LATIN.

1. PHÆDRUS'S FABLES OF AESOP.
2. OVID'S METAMORPHOSES. Book I.
3. VIRGIL'S ÆNEID. Book I.
4. PARSING LESSONS TO VIRGIL.
5. CÆSAR'S INVASION OF BRITAIN.

GREEK.

1. LUCIAN'S DIALOGUES. Selections.
2. THE ODES OF ANACREON.
3. HOMER'S ILIAD. Book I.
4. PARSING LESSONS TO HOMER.
5. XENOPHON'S MEMORABILIA. Part I.
6. HERODOTUS'S HISTORIES. Selections.

FRENCH.—SISMONDI; the BATTLES of CRESSY and POICTIERS.

GERMAN.—STORIES FROM GERMAN WRITERS.

** A Second Edition of the Essay, explanatory of the System, with an Outline of the Method of Study, is published. 12mo, sewed, price 6d.

ANIMAL MAGNETISM.

BARON Von Reichenbach's Researches on Magnetism, Electricity, Heat, Light, Crystallisation, and Chemical Attraction, in their Relation to the Vital Force. Translated and Edited (at the express desire of the Author) by DR GREGORY, of the University of Edinburgh. Cheap Issue. One Volume, 8vo, 6s 6d. cloth.

"The merits of this remarkable volume are great. The painstaking, conscientious, cautious, ingenious,—we had almost said the religious, and certainly the self-possessed enthusiasm with which the experimental clue is followed from turn to turn of the labyrinth, is surpassed by nothing of the same sort in the whole range of contemporary science."—*North British Review*.

ANATOMY, MEDICINE, &c.

DR. Quain's Anatomy. Edited by DR. SHARPEY and MR. QUAIN, Professors of Anatomy and Physiology in University College, London. Fifth Edition. Complete in Two Volumes, 8vo. Illustrated by four hundred Engravings on Wood. Price 2*l*.

Demonstrations of Anatomy. A Guide to the Dissection of the Human Body. By GEORGE VINER ELLIS, Professor of Anatomy in University College, London. Third Edition. Small 8vo. 12s. 6d. cloth.

The Essentials of Materia Medica, Therapeutics, and the PHARMACOPEIAS. For the use of Students and Practitioners. By ALFRED BARING GARROD, M.D., Professor of Materia Medica and Therapeutics in University College, London. Fcp. 8vo.

Lectures on the Principles and Practice of Midwifery. By EDWARD WM. MURPHY, A.M., M.D., Professor of Midwifery in University College, London. One Volume, 8vo, many Illustrations, 16s.

"The work will take rank among the best treatises on the obstetric art. By this work, Dr. Murphy has placed his reputation and his fame on a solid and durable foundation."—*Lubin Medical Press*.

A Handbook of Physiology. By WILLIAM SENHOUSE KIRKES, M.D., Demonstrator of Morbid Anatomy at St. Bartholomew's Hospital. Assisted by JAMES PAGET, Lecturer on General Anatomy and Physiology at St. Bartholomew's Hospital. Second Edition. One Volume 12mo, with Illustrations. 12s. 6d.

On Pain After Food; its Causes and Treatment. By EDWARD BALLARD, M.D., Lond., Lecturer on the Practice of Medicine at the School of Medicine adjoining St. George's Hospital. One vol. 4s. 6d. cloth.

Physical Diagnosis of the Diseases of the Abdomen. By EDWARD BALLARD, M.D., Late Medical Tutor in University College, London. Large 12mo, 7s. 6d. cloth.

"The profession is much indebted to Dr. Ballard for this unpretending little volume, which, we feel certain, if carefully studied, will accomplish its object of removing many of the difficulties at present surrounding the diagnosis of abdominal diseases."—*Lancet*.

A Practical Treatise on Diseases of the Heart and Lungs, their Symptoms and Treatment, and the Principles of Physical Diagnosis. By W. H. WALSHE, M.D., Professor of the Principles and Practice of Medicine and Clinical Medicine in University College, London; Physician to University College Hospital, and Consulting Physician to the Hospital for Consumption and Diseases of the Chest. A new and considerably enlarged edition. One Volume, 12s. 6d. cloth.

"This work is what its name indicates it to be—eminently practical. That it will add largely to the already great reputation of its author, no question can be entertained. It is far in advance of any other Treatise on Diseases of the Chest, either in this or any other country. Every page—we were about to say every line—contains a fact, often new, and *always resting on the Author's own observations*. Cases are quoted to prove every new statement, and to support every argument adduced in opposition to others. To the practitioner, the clinical teacher, and to the student, this work will prove alike invaluable."—*Medical Times*.

The Nature and Treatment of Cancer. By W. H. WALSHE, M.D., Professor of Medicine in University College, Physician to University College Hospital, and Consulting Physician to the Hospital for Consumption and Diseases of the Chest. One Volume, 8vo, with Illustrations. Cheap Issue, 6s. 6d.

The Diseases of the Rectum. By RICHARD QUAIN, F.R.S., Professor of Clinical Surgery in University College, and Surgeon to University College Hospital. With Lithographic Plates. Post 8vo. 7s. 6d. cloth.

"This Treatise is eminently of a practical character, and contains much original and valuable matter. It is not indeed a literary compilation, but rather an exposition of the author's opinions and practice in those diseases."—*Association Journal*.

The Science and Art of Surgery. Being a Treatise on Surgical Injuries, Diseases, and Operations. By JOHN ERICHSEN, Professor of Surgery in University College, and Surgeon to University College Hospital. 250 Wood Engravings. 8vo. 1l. 5s.

"The aim of Mr. Erichsen appears to be, to improve upon the plan of Samuel Cooper; and by connecting in one volume the science and art of Surgery, to supply the student with a text-book and the practitioner with a work of reference, in which scientific principles and practical details are alike included.

"It must raise the character of the author, and reflect great credit upon the College in which he is Professor, and we can cordially recommend it as a work of reference, both to students and practitioners."—*Medical Times*.

The Microscopic Anatomy of the Human Body in Health AND DISEASE. Illustrated with numerous Drawings in Colour. By ARTHUR HILL HASSALL, M.B., Fellow of the Linnaean Society, Member of the Royal College of Surgeons, &c. &c. Two Vols. 8vo, 2l. 5s.

Hassall's History of the British Freshwater Algae, including Descriptions of the Desmidæ and Diatomaceæ. With upwards of 100 Plates, illustrating the various species. Two Vols. 8vo, 2l. 5s.

Morton's Surgical Anatomy of the Principal Regions.

Completed by Mr. CADGE, late Assistant Surgeon, University College Hospital. Twenty-five Lithographic Illustrations Coloured, and Twenty-five Woodcuts. Royal 8vo, 2ls. cloth lettered.

"The work thus completed constitutes a useful guide to the student, and remembrancer to the practitioner. We can speak very favourably of the general execution of the work. The coloured lithographs are, for the most part, well drawn, and faithfully represent the broad features of the several parts. The woodcuts are well engraved, and very clearly exhibit the points which they are intended to illustrate."—*Medical Gazette*.

A Series of Anatomical Plates in Lithography. Edited by JONES QUAIN, M.D., and ERASmus WILSON, F.R.S.

* * * A remarkably cheap issue is now in course of delivery to Subscribers at the following low prices:—

THE COMPLETE WORK, in Two Volumes, Royal Folio, Half-bound Morocco	To Subscribers.		Former Price.	
	£ s. d.	£ s. d.	£ s. d.	£ s. d.
THE SAME, Full Coloured, Half-bound Morocco :	8 8 0		14 0 0	

The Work may also be subscribed for in separate portions, bound in Cloth and Lettered, as follows:—

	PLAIN.		COLOURED.	
	To Subscribers.	Former Price.	To Subscribers.	Former Price.
Muscles. 51 Plates	1 5 0	1 18 0	— 2 4 0	3 12 0
Vessels. 50 Plates	1 5 0	1 18 0	— 2 0 0	3 3 0
Nerves. 38 Plates	1 1 0	1 10 0	— 1 14 0	2 16 0
Viscera. 32 Plates	0 17 0	1 5 0	— 1 10 0	2 8 0
Bones and Ligaments. 30 Plates	0 17 0	1 5 0	— 1 0 0	1 11 6

* * * Proposals with full particulars may be had of the Publishers, by whom and by all Booksellers, Subscribers' names will be received.

On Gravel, Calculus, and Gout; chiefly an Application of Professor Liebig's Physiology to the Prevention and Cure of those Diseases. By H. BENCE JONES, M.D., F.R.S., Physician to St. George's Hospital. 8vo, 6s. cloth.

CHEMISTRY, &c.

Principles of Agricultural Chemistry, with Special Reference to the late Researches made in England. By JUSTUS VON LIEBIG, Professor of Chemistry in the University of Munich. Small 8vo, 3s. 6d. cloth. *Just published.***FAMILIAR Letters on Chemistry.** In its relations to Physiology, Dietetics, Agriculture, Commerce, and Political Economy. By JUSTUS VON LIEBIG. A New and Cheap Edition, revised throughout, with many additional Letters. Complete in one Volume, Foolscape 8vo, price 6s. cloth.**Practical Pharmacy.** The Arrangements, Apparatus, and Manipulations of the Pharmaceutical Shop and Laboratory. By FRANCIS MOHR, Ph. D., and THEOPHILUS REDWOOD, Professor of Chemistry and Pharmacy to the Pharmaceutical Society. 400 Engravings on Wood. 8vo, 6s. 6d. cloth.**Gregory's Handbook of Inorganic Chemistry.** For the use of Students. By WILLIAM GREGORY, M.D., Professor of Chemistry in the University of Edinburgh. Third Edition, revised and enlarged. 12mo, 5s. 6d.

"A young man who has mastered these few and by no means closely printed pages, may venture to face any board of examiners on Chemistry, without fear of being posed by any fair question."—*Association Journal*.

Gregory's Handbook of Organic Chemistry; being a New and greatly Enlarged Edition of the "Outlines of Organic Chemistry, for the Use of Students." One volume, large 12mo, 9s. 6d. cloth.

Handbook of Organic Analysis. By JUSTUS LIEBIG. Edited by DR. HOFMANN, Professor in the Royal College of Chemistry, London. Large 12mo. Illustrated by 85 Wood Engravings. 5s. cloth.

"The work now before us is a most valuable contribution to our knowledge on this most important subject. The style is lucid, and the processes are not only explained to the mind, but are made manifest to the eye by a profusion of beautiful illustrations."—*Medical Times*.

Handbook of Inorganic Analysis. By FRIEDRICH WÖHLER, M.D., Professor of Chemistry in the University of Gottingen. Translated and Edited by DR. HOFMANN, Professor in the Royal College of Chemistry, London. Large 12mo. 6s. 6d. cloth.

"Next to Rose of Berlin in the ranks of living analytic chemists, particularly in the inorganic department of the art, stands Friedrich Wöhler, who has in this book given us a compendium of inorganic analysis, illustrated by examples of the methods to be pursued in the examination of minerals, both of a simple and complex constitution, which, if followed out by the student with ordinary care and patience, and with some little practical instruction, will not fail to render him a thorough master of this division of chemical knowledge."—*Association Journal*.

Elements of Chemical Analysis, Qualitative, and Quantitative.

By EDWARD ANDREW PARNELL, author of "Applied Chemistry; in Arts, Manufactures, and Domestic Economy." Second Edition, revised throughout, and enlarged by the addition of 200 pages. 8vo, Cheap Issue, 9s. cloth.

Animal Chemistry; or, Chemistry in its Applications to PHYSIOLOGY AND PATHOLOGY. By JUSTUS LIEBIG, M.D. Edited from the Author's Manuscript, by WILLIAM GREGORY, M.D. Third Edition, almost wholly re-written. 8vo, Part I. (the first half of the work) 6s. 6d. cloth.

Chemistry in its Application to Agriculture and Physiology.

By JUSTUS LIEBIG, M.D. Edited from the Manuscript of the Author, by LYON PLAYFAIR, Ph. D., and WM. GREGORY, M.D. Fourth Edition, revised. Cheap Issue. 8vo, 6s. 6d.

Dyeing and Calico Printing. By EDWARD ANDREW PARNELL, Author of "Elements of Chemical Analysis." (Reprinted from Parnell's "Applied Chemistry in Manufactures, Arts, and Domestic Economy, 1844.") With Illustrations. 8vo, 7s. cloth.

Outlines of the Course of Qualitative Analysis followed in the GIESSEN LABORATORY. By HENRY WILL, Ph. D., Professor Extraordinary of Chemistry in the University of Giessen. With a Preface by BARON LIEBIG. 8vo, 6s., or with the Tables mounted on linen, 7s.

Turner's Elements of Chemistry. Edited by Professors LIEBIG and GREGORY. Eighth Edition. 1 Vol. 8vo, 1l. 10s.

COMMON-PLACE BOOKS AND LITERARY DIARIES.

THE Private Diary. Arranged, Printed, and Ruled for receiving an account of every day's employment for the space of one year. With an Index and Appendix. Cheaper Edition. Post 8vo, strongly half-bound, 3s. 6d.

The Student's Journal. Formed on the plan of the "Private Diary." Cheaper Edition. Post 8vo, strongly half-bound, 3s. 6d.

The Literary Diary; or Complete Common-Place Book, with an Explanation and an Alphabet of Two Letters on a Leaf. Cheaper Edition. Post 4to, ruled throughout, and strongly half-bound, 8s. 6d.

A Pocket Common-place Book. With LOCKE'S INDEX. Cheaper Edition. Post 8vo, strongly half-bound, 6s. 6d.

DRAWING, &c.

LINEAL Drawing Copies for the Earliest Instruction. Comprising 200 subjects on 24 sheets, mounted on 12 pieces of thick pasteboard. By the Author of "Drawing for Young Children." In a portfolio. 5s. 6d.

Easy Drawing Copies for Elementary Instruction. By the Author of "Drawing for Young Children." Set I. Twenty-six Subjects mounted on pasteboard. Price 3s. 6d., in a Portfolio. Set II. Forty-one Subjects mounted on pasteboard. Price 3s. 6d., in a Portfolio.

* * The Work may also be had (two sets together) in one Portfolio, price 6s. 6d.

Drawing Models. Consisting of Forms for Constructing various Buildings, Gateways, Castles, Bridges, &c. The Buildings will be found sufficiently large to be drawn from by a numerous Class at the same time. In a Box, with a small Treatise on Drawing and Perspective. Price 2l. 10s. Length of the Box, 18½ inches; breadth 13 inches; height 8½ inches.

Drawing Materials. A Quarto Copybook of 24 leaves, common paper, 6d. A Quarto Copybook of 24 leaves, paper of superior quality, 1s. 3d. A Quarto Copybook of 60 leaves, 1s. 6d. Pencils, with very thick lead, B.B.B. 2s. per half-dozen. Pencils, with thick lead, F. at 1s. 6d. ditto. Drawing Chalk, 6d. per dozen sticks, in a Box. Port-crayons for holding the Chalk, 4d. each.

Perspective. Its Principles and Practice. By G. B. MOORE. In two parts, Text and Plates. 8vo, cloth, 8s. 6d.

The Principles of Colour applied to Decorative Art. By G. B. MOORE, Teacher of Drawing in University College, London. Fcap. 2s. 6d.

SINGING.

THE Singing Master. People's Edition. (One-Half the Original Price.) Sixth Edition. 8vo. 6s. cloth lettered.

"What chiefly delights us in the 'Singing Master' is the intermixture of many little moral songs with the ordinary glees. These are chiefly composed by Mr. Hickson himself; and we could scarcely imagine anything of the kind better executed. They relate to exactly the class of subjects which all who wish well to the industrious orders would wish to see imprinted on their inmost nature—contentment with their lowly but honourable lot, the blessings that flow from industry, the fostering of the domestic affections, and aspirations for the improvement of society."—*Chambers' Journal*.

* * Sold also in Five Parts, any of which may be had separately as follows:—

FIRST LESSONS IN SINGING AND THE NOTATION OF MUSIC. Containing Nineteen Lessons in the Notation and Art of Reading Music. 8vo, 1s. sewed.

RUDIMENTS OF THE SCIENCE OF HARMONY OR THOROUGH BASS. 8vo, 1s. sewed.

THE FIRST CLASS TUNE BOOK. A selection of thirty single and pleasing airs, arranged with suitable words for young children. 8vo, 1s. sewed.

THE SECOND CLASS TUNE BOOK. A selection of Vocal Music adapted for youth of different ages, and arranged (with suitable words) as two and three-part harmonies. 8vo, 1s. 6d.

THE HYMN TUNE BOOK. A selection of Seventy popular Hymn and Psalm Tunes, arranged with a view of facilitating the progress of children learning to sing in parts. 8vo, 1s. 6d.

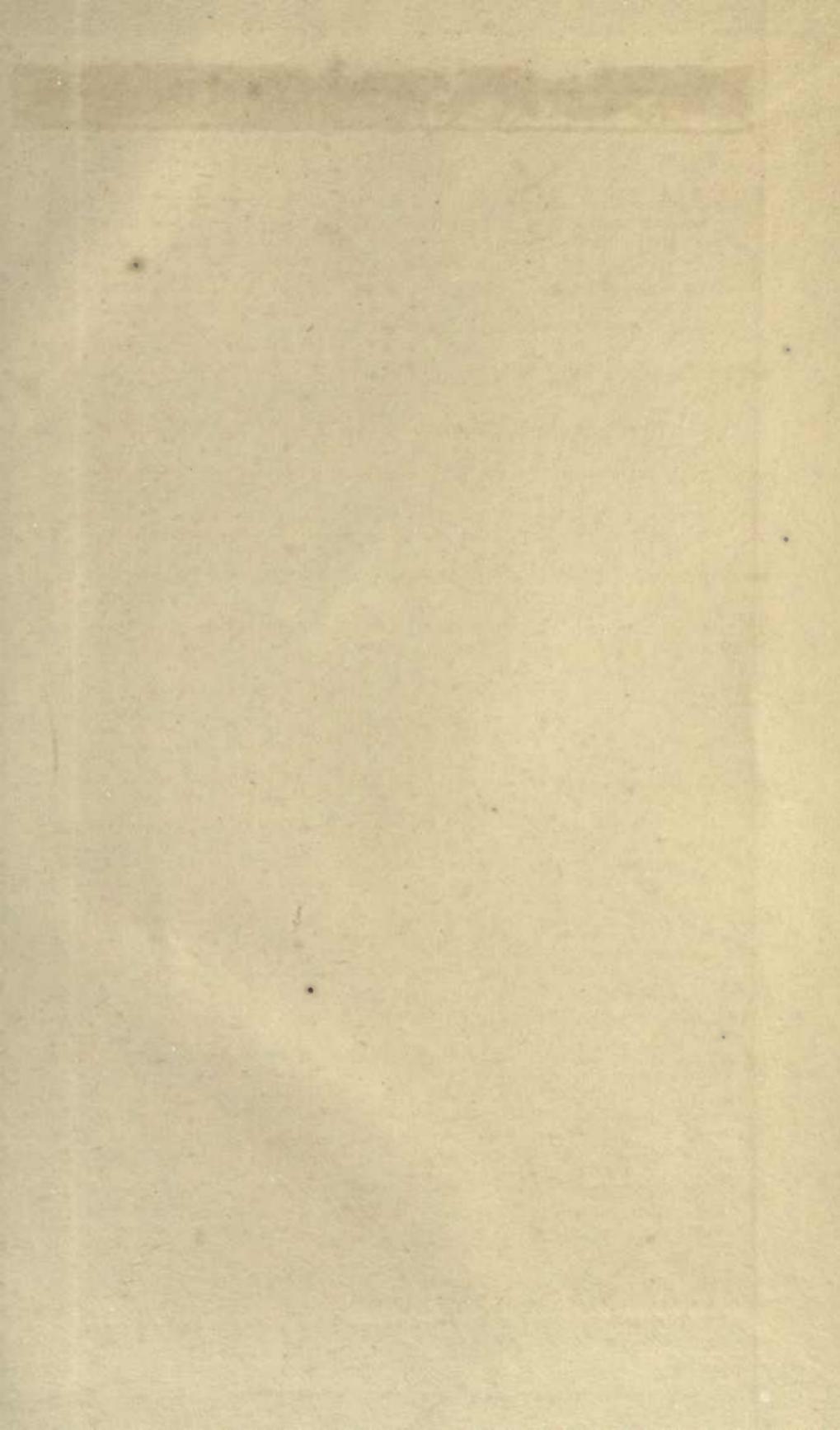
The words without the Music may be had in three small books as follows:—

MORAL SONGS, from the FIRST CLASS TUNE BOOK. 1d.

MORAL SONGS, from the SECOND CLASS TUNE Book, 1d.

HYMNS from the HYMN TUNE Book, 1½d.

* * The Vocal Exercises, Moral Songs, and Hymns, with the Music, may also be had, printed on Cards, price Twopence each Card, or Twenty-five for Three Shillings.



RETURN TO the circulation desk of any
University of California Library
or to the

NORTHERN REGIONAL LIBRARY FACILITY
Bldg. 400, Richmond Field Station
University of California
Richmond, CA 94804-4698

ALL BOOKS MAY BE RECALLED AFTER 7 DAYS
2-month loans may be renewed by calling
(415) 642-6753
1-year loans may be recharged by bringing books
to NRLF
Renewals and recharges may be made 4 days
prior to due date

DUE AS STAMPED BELOW

NRLF LIBRARY USE NOV 26 '90

